The Electron Book

BASIC, Sound and Graphics

Jim McGregor & Alan Watt

Exploring the Electron

This is a book that no Electron owner will want to miss. It will guide you step-by-step from the moment when you first plug in and switch on to a stage where you'll be making full use of the Electron's capabilities.

BASIC the Electron's programming language is described clearly and simply in such a way that you'll be writing programs at an early stage. Then in the second half of the book you can explore the exciting world of sound, graphics and animation. Soon you'll be

- ★ inventing and playing games
- ★ writing and listening to music
- ★ producing and watching animated graphics

all in the comfort of your own front room.

A further book **Advanced Programming Techniques for the Electron** by the same authors contains ideas for even more exciting programs and projects. There is a whole world waiting to be explored, and the voyage of discovery begins on page one of **The Electron Book: BASIC, Sound and Graphics.**

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Advanced Programming Techniques for the Electron
Jim McGregor Alan Watt

Assembly Language Programming on the Electron
John Ferguson Tony Shaw

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JIM McGREGOR

ALAN WATT

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Preface

The first half of this book is an introduction to programming in BASIC for the ACORN Electron. The second half of the book is a comprehensive guide to the more advanced features of this powerful computer. The book can be used by complete beginners or by anyone who already has some experience in BASIC programming on other machines.

The BASIC dialect on the Electron computer is the same as that used on the BBC Micro. Electron BASIC contains many features not usually found in microcomputer BASIC and these are exploited extensively in the book. Structured programming is introduced at an early stage and used throughout. In this respect the book is emphatically not another standard BASIC book re-hashed. The material in it has been written specially for BBC and Electron BASIC. Well over half the book (Chapter 8 onwards) deals exclusively with colour, graphics, animation and sound. In addition, elementary use of sound and graphics appears in earlier chapters.

Throughout the book general ideas are introduced by means of example programs. Considerable care has been taken to make sure that the programs are readable and they can be viewed almost as part of the text rather than a tangle that needs careful unravelling. There are a large number of suggested exercises because, in the end, programming is a practical art that can only be acquired by doing it.

The book is meant to be self contained and although the User Guide is always a necessary reference, most of the material that you will require for day to day programming is contained herein. Some of the more detailed technical information is to be found in the ten appendices at the end of the book.

A mastery of the material in this book will mean that you have acquired a good deal of expertise and your programming ability should be limited only by your imagination. Too often people stop programming at a certain level of complexity because they see the work involved as being too difficult. Often 'too difficult' means 'too tedious and detailed'. Using the structured programming techniques described in this book should help to remove this artificial block.

Are you a slow typist?

You can experiment with the programs described in this book without having to type them. All the programs are available on a computer cassette and you can work through the cassette as you work through the book.

Some of the longer programs on the cassette are

- Stock control (Chapters 6 and 7)
- Composite images and image planes (Chapter 9)
- 'Rubber banding' and 'picking and dragging' (Chapter 9)
- Playing tunes (Chapter 10)
- The keyboard as an organ (Chapter 10)
- Animated games (Chapter 11)
- Character design program (Chapter 11)
- Spinning discs and spirals (Chapter 11)

Programs are also available on cassette for the companion volume by the same authors:

Advanced programming techniques
for the ACORN Electron

Books and cassettes are available from your bookseller or direct from

Addison-Wesley Publishers Ltd.,
53 Bedford Square,
London, WC1B 3DZ.

Introduction

In this introductory chapter, we shall use some very simple Electron BASIC programs to introduce a number of general points about using your computer. If you are not familiar with the use of a typewriter keyboard, you should refer to the start of Appendix 1. We assume that you have connected your computer to your television set, switched on and tuned the television if necessary. When you have done this, you should see a display like the following on the screen:

```
ACORN Electron

BASIC

>
```

The symbol '>' is displayed by the computer whenever it is waiting for you to tell it what to do next. Try typing

```
PRINT 43 + 26
```

You must press the RETURN key at the end of every line that you type. The computer will not pay any attention to anything you type until you press this key. If you make a mistake on the line before you press the RETURN key, you can change the line by using the DELETE key to delete as many characters as you like. When you press the RETURN key at the end of the above line, the computer should immediately 'print'

```
        69
```

on the screen. We have given the computer a single BASIC instruction and it has been obeyed immediately - the computer can be used like a rather sophisticated calculator. Instructions written in BASIC are often referred to as 'statements'.

Storing a program

The big advantage that a computer has over a calculator is that a list of instructions can be stored inside the computer. Such a list of instructions is called a 'program'

and, once stored in the computer, the instructions in a program can be obeyed again and again. If we want the computer to store a line of BASIC as part of a program, we must number the line. The lines in a program are stored in the order determined by these numbers. Try typing:

```
1  PRINT 43 + 26
```

Nothing will happen, but the computer has stored this instruction as line 1 of a program. Now type:

```
2  PRINT 43 * 26
```

(The '*' is used as a multiplication sign to avoid confusion with the letter 'x'.) The computer now has two lines stored away. In order to convince yourself that the computer has stored these lines, type the command:

```
LIST
```

and the computer will display a list of the lines in your program so far. If you want the computer to obey the instructions in your program you must tell it to 'run' the program by typing the command:

```
RUN
```

This will make the computer obey the statements in the program one after another in the order in which they are stored. In this case, the computer will print:

```
 69
1118
```

The lines in a program do not need to be numbered from 1 upwards, nor do the numbers need to go up in steps of 1. Type the command:

```
NEW
```

to tell the computer to erase the old program in order that we can type a new one. Now type the same program as before but with different line numbers.

```
10  PRINT 43 + 26
20  PRINT 43 * 26
```

You can now LIST or RUN the program as before, but the advantage of numbering the lines in steps of 10 is that new lines can be easily inserted. For example, type:

```
15  PRINT 43 - 26
```

and LIST the program. You will find that this new line has been inserted between lines 10 and 20. When you run the program, three values are printed on the screen.

You should get into the habit of numbering the lines of all your programs in steps of 10.

Programs and INPUT

We said above that an important feature of a computer is its ability to store a program and run it again and again. Doing this with the program we typed above is not very useful - the same answers are printed every time it is run. When we write a program, we usually describe the operations that the program is to carry out without specifying the actual values to be used in these operations. We do this by giving names to the values involved and describing an operation in terms of these names. Use the NEW command to clear away the old program and type:

```
10  PRINT length*width
```

This BASIC instruction describes the process of multiplying two values to which we have given the names 'length' and 'width'. These names might refer to the length and width of a room for which we wish to calculate the floor area.

Before this program can be successfully run, arrangements must be made to tell the computer what values to use for the variables 'length' and 'width'. Try running the program as it stands and the computer will display the error message:

```
No such variable at line 10
```

This simply means that the computer does not know what values to use in calculating 'length*width'.

There are various ways in which values could be provided for our two variables, but by far the commonest and most important is to tell the computer that we are going to 'input' these values when the program is running. We can do this by adding the following statement to the program:

```
 5  INPUT length, width
```

The complete program now consists of two statements:

```
 5  INPUT length, width
10  PRINT length*width
```

Now run the program. You will find that a question-mark appears on the screen and nothing further happens. The

computer is trying to obey the statement on line 5 and is waiting for you to INPUT values for 'length' and 'width'. Type two numbers, separated by a comma, for example:

```
6, 3
```

These two values are given to the two variables in the INPUT statement. 'Length' is given the value 6 and 'width' is given the value 3. Only once these two values have been typed can the computer go on and obey the PRINT statement and display the answer:

```
18
```

If you run the same program again, you can input different values and get different answers. This program is much more generally useful than the one we wrote in the last section. The same program can be used for calculating the area of a different room each time it is run.

The use of named variables in a program is fundamental. A program written in terms of names specifies a general task that is carried out using particular values when the program is obeyed. The particular values can be provided via INPUT statements or, as we shall see later, they may be calculated by the program itself from input values.

We shall present more information about doing calculations in the next chapter. In the remaining two sections of this chapter, we shall present simple programs that introduce two of the most exciting features of your Electron - its ability to draw pictures and make sounds.

Drawing pictures

The computer graphics facilities on the Electron are very sophisticated and techniques for using graphics are extensively illustrated throughout this book. In order to give you a taste of what can be done, here is a short graphics program for you to type into your machine.

```
 10  MODE 0
 20  MOVE 570, 570
 30  DRAW 700, 740  :  DRAW 900, 660
 40  DRAW 730, 680  :  DRAW 640, 500
 50  DRAW 740, 440  :  DRAW 660, 370
 60  DRAW 600, 460  :  DRAW 460, 370
 70  DRAW 380, 110  :  DRAW 400, 430
 80  DRAW 530, 530  :  DRAW 490, 570
 90  DRAW 480, 590  :  DRAW 490, 600
100  DRAW 510, 600  :  DRAW 570, 570
```

When you run this program, you will find that it produces a

line-drawing on your screen.

Incidentally we would not normally write such a program by repeating sixteen DRAW statements and better ways of writing such a program are given later. Also note the use of colons to separate statements typed on the same line.

The instruction on line 10 tells the computer to switch to MODE 0. The computer can be in any one of several different 'states' or 'modes' and the MODE 0 instruction switches the computer into one of the modes in which it can draw pictures. After running the above program, the computer remains in MODE 0 and you will find that the characters in this mode are rather small. You can switch the computer back to its 'normal' mode by typing the instruction

```
MODE 6
```

(without a line number).

When the computer is in one of its graphics modes, we can imagine the screen to be marked out like a piece of graph paper. There are 1279 squares across the screen and 1023 squares up the screen. The instruction:

```
MOVE 200,700
```

moves an imaginary pen to the point that is 200 squares across the screen from the left and 700 squares up the screen.

```
DRAW 1000,700
```

Draws a line from the last point visited to the point that is 1000 squares across and 700 squares up. You should now be able to see how the above program works and you should even be able to write some programs of your own to produce simple line-drawings.

Making sounds

Here is a short program that makes use of the sound generator on the Electron:

```
10  SOUND 1, -15,  53, 20
20  SOUND 1, -15,  69, 20
30  SOUND 1, -15,  81, 20
```

When you run this program, it plays three notes of a major chord (doh, me, soh), starting on Middle C. The notes are played separately one after another. A detailed explanation of the various parts of the SOUND statement is best left until later, but the third number determines the pitch of of the note played. We can make the chord program more flexible:

```
10  INPUT pitch
20  SOUND 1, -15, pitch, 20
30  SOUND 1, -15, pitch + 16, 20
40  SOUND 1, -15, pitch + 28, 20
```

Try running this program. When the question-mark appears, you should input a number (between 0 and 227). The number you input determines the starting note. If you are musically inclined, you can use this program to work out how the pitch number in a sound statement corresponds to the notes on the piano.

Some general information and advice on typing programs appears in Appendix 1. As your programs get longer and more interesting, you will want to save them on cassette. Information on how to do this appears in Appendix 2.

By now you should be starting to find your way around your computer. Before you can make full use of its potential there is a great deal to learn, so read on!

Chapter 1 Communicating with your programs

In this chapter, we describe in more detail various ways of getting information into and out of programs. Input information can consist of numbers and words typed at the keyboard and output information might include numbers, words and pictures displayed on the screen or sounds made by the sound generator. More advanced applications might involve input of signals from an analogue device such as a games paddle or the output of spoken words using a speech synthesizer.

1.1 Input of numeric values

The simple area calculation program of the introductory chapter contained the statements (renumbered)

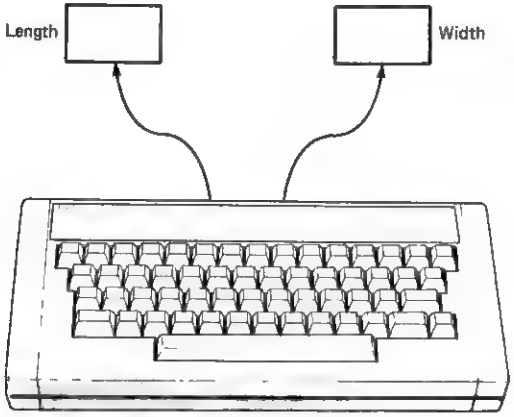
```
10   INPUT length, width
20   PRINT length*width
```

'Length' and 'width' are the names of two 'variables' that can be given numeric values. In our introductory chapter, we saw how the use of named variables allows us to describe a task in general terms and supply the actual values to be used later when the program is obeyed. It is useful to think of a variable as a named box or 'memory location' in which a program can store a value:

We say that 'length' is the name of a box containing 5 and 'width' is the name of a box containing 4. Of course the boxes 'length' and 'width' need not necessarily contain the numbers 5 and 4. They can contain any numbers we choose, for example:

This is why we use the term 'variable'.

The INPUT statement tells the computer that the values are going to be input from the keyboard when the program is running. When the program is run and the INPUT statement is obeyed, the computer will wait until two numbers are typed at the keyboard and these values are then stored in the variables 'length' and 'width':



The program then continues running and evaluates the expression

```
length*width
```

using the values for 'length' and 'width' that are contained in the boxes with these names. These are the values that have just been supplied from the keyboard.

When the numbers required by an INPUT statement are being typed at the keyboard, they can all be typed on one line separated from each other by commas, or they can typed on separate lines, the RETURN key being pressed after each number.

When we run the above program, the question mark is all that appears on the screen to remind us that the computer is expecting some input. When a program expects input from the keyboard, it is good programming practice to arrange for it to display a message telling the user of the program what to type. This makes our programs easier for other people to use. We can make our area program do this:

```
10   INPUT "Length of room", length
20   INPUT "Width of room",  width
30   PRINT length*width
```

Each INPUT statement in this amended version of the program includes a 'string' in double quotation marks before the variable for which an input value is required. When the program is run, any string included in an INPUT statement will be displayed on the screen (without the quotation marks) before the computer waits for the next value to be typed. This acts as a 'prompt', telling the user what the program expects him to type next.

When we run this version of the program, a display such as the following is produced:

```
>RUN
Length of room?5
Width of room?4
        20
```

The question marks have been inserted automatically by the computer. If the comma after a string in an INPUT statement is omitted, then the question mark is suppressed and this is occasionally desirable.

1.2 Choice of names for numeric variables

In the last section, 'length' and 'width' were used in a program as the names of two 'variables' in which numbers were stored by the program when it was run. The programmer is free to choose the names that he wants to use for his variables. However, he must not choose a name that can be confused with a BASIC 'keyword'. PRINT and INPUT are examples of keywords and words such as these cannot be used as the names of variables. Nor can we use names that start with BASIC keywords. All the BASIC keywords are typed in capital letters and the above restriction can be ignored if we use small letters for the names of all our variables.

You should choose mnemonically meaningful names. For example in the above context choose the names 'length' and 'width' rather than 'l' and 'w', or, worse still 'a' and 'b'. This makes it much easier for a program to be read and understood by other people, or by yourself in the future if you wish to develop it further.

Names can be of any length. Spaces cannot be typed in the middle of a word, but this is not too inconvenient. It means you must use, for example, 'nooftimes' rather than 'no of times'. However, the underline character can be used in a variable name and this can be used to distinguish separate words in a composite name. For example, we could call the above variable 'no_of_times'.

Finally, if a variable can take only integer (whole

number) values, we can tell the computer this by adding a percent sign, '%', to the end of the variable name. Values stored in integer variables are stored differently from values in other numeric variables and integer arithmetic uses less computer time than real arithmetic. (A 'real' is a number that may have a fractional part.) We shall use integer variables only where speed of program execution is critical, in applications such as animation which is discussed in Chapter 11.

1.3 More about PRINT

In the last section, a simple PRINT statement was used to tell the computer to calculate the value of an expression and print the result obtained. A PRINT statement can in fact contain a list of several items to be printed. For example, we can make the output produced by the program more informative by using:

```
30   PRINT "Area: "; length*width; " square metres."
```

Incidentally, when you type this line of BASIC in MODE 6 you will find that it will not fit onto one line on the screen. This does not matter. When you get to the right hand edge of the screen, just carry on typing without pressing RETURN and the line you are typing will automatically overflow onto the next screen line. You must not press the RETURN key because this would indicate that the end of the PRINT statement had been reached. A single numbered line in a BASIC program can occupy up to 240 characters (6 screen lines in MODE 6).

The above PRINT statement contains a list of three items to be printed - two strings and an expression. The items are separated from each other by semicolons. When the PRINT statement is obeyed, each item in the list tells the computer to print something. A string between double quotation marks is copied onto the screen character by character exactly as it appears in the program. If an item is not enclosed in quotation marks, then the computer prints a value, possibly after doing a calculation to obtain the value. An item in a PRINT list may be just a single variable name, in which case the value stored in the variable is printed.

When the above PRINT statement is obeyed, the display produced is:

```
Area: 20 square metres.
```

The following table shows what output is produced by various PRINT statements if the variables 'x' and 'y' contain the values shown:

statement	computer prints
`PRINT x`	`7`
`PRINT y`	`2`
`PRINT "x contains "; x`	`x contains 7`
`PRINT "y contains "; y`	`y contains 2`
`PRINT "sum of x,y is "; x + y`	`sum of x,y is 9`
`PRINT "sum of "; x; ","; y;" is ";x+y`	`sum of 7,2 is 9`
`PRINT "x + y = "; x + y`	`x + y = 9`
`PRINT x; " + "; y; " = "; x + y`	`7 + 2 = 9`

You should examine carefully the differences in the effects of the last four statements.

Each PRINT statement starts printing on a new line on the screen, unless the previous PRINT statement was terminated by a semicolon. We can also use a PRINT statement with no items. This has the effect of displaying a blank line on the screen (unless the previous PRINT statement terminated with a semicolon in which case it simply starts a new line).

Here is a complete program that calculates a taxpayer's annual tax bill and displays the details on the screen. The input to the program consists of his annual income and his total tax allowance. We assume that tax is deducted at a rate of 30% of taxable income.

```
 10   INPUT "Annual income", income
 20   INPUT "Tax allowance", allowance
 30   CLS
 40   PRINT
 50   PRINT
 60   PRINT
 70   PRINT "**************************"
 80   PRINT "Income : "; income
 90   PRINT "Allowance : "; allowance
100   PRINT "Taxable income : "; income - allowance
110   PRINT "Tax due : "; (income-allowance)*0.3
120   PRINT "**************************"
```

The brackets at line 110 are needed to ensure that the allowance is subtracted from the income before multiplication by 0.3. The CLS statement at line 30 has the effect of clearing the screen and the three PRINT statements at lines 40, 50 and 60 insert three blank lines at the top of the screen. Actually, several BASIC statements can be typed on one numbered line of a program, provided that we put colons between the statements. Thus, lines 30 to 60 could be replaced by:

```
30   CLS : PRINT : PRINT : PRINT
```

If you run the above program, you will find that after the initial input has been typed, the computer will produce a display such as:

```
**************************
Income : 9563
Allowance : 2500
Taxable income : 7063
Tax due : 2118.9
**************************
```

It would be nice if numbers representing sums of money were displayed with two digits after the decimal point, but we shall not worry about how to do this for the time being.

If the items in a PRINT statement are separated by commas, then the items printed are more widely spaced than they are if semicolons are used. This facility is needed if we want to tabulate values in columns and we shall leave the details until later. For the time being, you could try replacing the semicolons in the above program with commas and observe the effect. Details about the layout of output produced by PRINT statements appear in Appendix 6.

1.4 Storing the results of calculations

You have seen several programs in which we asked the computer to do simple calculations and print the answers obtained. We tell the computer to do a calculation by writing an arithmetic expression such as:

```
length*width
x+y
(income-allowance)*0.3
```

It is often convenient to arrange for a program to remember the results of a calculation by storing the result in a variable for use later by the same program. For example, a program to add up four examination marks and display the total and the average could be written as:

```
10   INPUT "Four marks:", m1,m2,m3,m4
20   PRINT "Total:"; m1 + m2 + m3 + m4
30   PRINT "Average:"; (m1 + m2 + m3 + m4)/4
```

The symbol '/' is the sign we use for 'divided by'. In this program, the computer adds together the four marks at line 20 and then repeats the same calculation at line 30 before dividing the total by 4. An alternative version of the program is:

```
10   INPUT "Four marks:", m1,m2,m3,m4
20   totalmark = m1 + m2 + m3 + m4
30   PRINT "Total:"; totalmark
40   PRINT "Average:"; totalmark/4
```

The statement at line 20 is known as an 'assignment' statement. The value of the expression on the right of the equals sign is 'assigned to' or stored in the variable whose name appears on the left. Thus the four marks are added together once only and the total is stored in the variable 'totalmark'. The value of this variable is then used by the two PRINT statements and the calculation does not have to be done again.

An important advantage of using variables for storing the values of expressions is that we can give meaningful names to the variables and thus make the meaning of the program more obvious.

As another example, lines 100 and 110 of the tax program could be replaced by:

```
100   taxable = income - allowance
105   PRINT "Taxable income : "; taxable
110   PRINT "Tax due : "; taxable*0.3
```

In the next chapter, we shall look in more detail at the use of assignment statements and mathematical expressions, but the information given above should suffice for the time being.

Exercises

1 Write a program that accepts as input a person's current bank balance and the amount of a withdrawal. The program should print out his new balance.

2 A pay rise of 12.5% has been awarded to a firm's employees and it is to be backdated by 7 months. Write a program to which an employee can supply as input his previous annual salary and which will inform him how much additional backdated pay he should receive.

3 Write a program that draws a Christmas tree outline using asterisks and which displays the message 'A Merry Christmas' in the centre of the tree.

4 Write a program which prints your first initial in the form of a letter several lines high, for example:

```
      JJ
      JJ
      JJ
      JJ
JJ    JJ
JJJJJJJJ
  JJJJ
```

5 Write a program that inputs two integers and reports their sum and product in the form of two equations.

For example, if the input is:

```
4, 7
```

the display produced should be:

```
4 + 7 = 11
4 * 7 = 28
```

6 Write a program that inputs the gross price of an item sold and a discount rate (as a percentage). The program should display a sales invoice, for example:

```
**********************
Gross price      56.25
Discount rate     2.50
Discount          1.41
Discount price   54.84
**********************
```

Do not worry at this stage about producing precisely the above layout.

7 Write a program that displays the perimeter, floor area, wall area and volume of a room given its length, width and height. The program should not repeat any calculations unnecessarily.

1.5 String variables

The programs that we have seen so far have all involved the processing of numerical input. Many important computer applications involve processing input that consists of strings of characters. A character may be a letter of the alphabet, a space, a punctuation mark, or any other symbol that can be typed at a keyboard. For example, a data processing application may involve writing programs that handle lists of names and addresses. Another example is a

word processor which is simply a computer that has been programmed to accept input of typed documents.

In BASIC, we can indicate that we want to store strings of characters in a variable by adding a dollar sign, '$', at the end of the variable's name. Such a string variable can be pictured as a box in which we can store a sequence of up to 255 characters (letters, punctuation marks, etc.). A common use of string variables is to store words. Here is an example of a program that requires input of a word instead of a number:

```
10   CLS
20   INPUT "What is your name", name$
30   PRINT "Hello, "; name$; ". I'm pleased to meet you."
```

If you run this program, it clears the screen and displays the question:

```
What is your name?
```

The question mark has been added by the computer to indicate that it expects some input. It is waiting for you to type some characters to be stored in the variable 'name$'. If you type the word "Jim" and press the RETURN key, then the display will be completed as follows:

```
What is your name?Jim
Hello, Jim. I'm pleased to meet you.
```

Note the way in which punctuation marks and spaces are inserted at appropriate places in the display by including them inside quotation marks in the PRINT statement. Incidentally, if you want to insert a quotation mark in a string, you must type it twice to indicate that it does not mark the end of the string.

After the computer has obeyed the INPUT statement, the variable 'name$' has the word "Jim" stored in it:

Whatever name is typed as input for the program is stored in the variable and the program can subsequently be made to do anything we wish with that name. For example, we could extend the program:

```
40   PRINT "Bonjour, "; name$; "."
50   PRINT "Ciao, "; name$; "."
```

An example of the display produced when we run this extended version of the program is:

```
What is your name?Alan
Hello, Alan. I'm pleased to meet you.
Bonjour, Alan.
Ciao, Alan.
```

where the user at the keyboard has typed the word "Alan" after the question mark.

A string does not necessarily consist of a single word. The user of the above program could type first names and surnames before pressing RETURN and that would count as one string. For example:

```
What is your name?Harry B. Frackentackle
Hello, Harry B. Frackentackle. I'm pleased to meet you.
Bonjour, Harry B. Frackentackle.
Ciao, Harry B. Frackentackle.
```

An input string can be terminated by the RETURN key or by a comma. For example, if we run the following program, we can input name and age on one line with a comma in between:

```
10   INPUT "Name and age", n$, age
20   PRINT n$; ", you are "; age; " years old."
30   PRINT "Next birthday, you are "; age + 1
```

The display produced might be:

```
>RUN
Name and age? Fred, 23
Fred, you are 23 years old.
Next birthday, you are 24
```

where the information after the question mark has been typed by the user.

Spaces typed before an input string are ignored. If you want an input string to start with a space or to include a comma, then one way of achieving this is to type the string in quotation marks:

```
10   PRINT "What do you need to buy"
20   INPUT shopping$
30   PRINT "Don't forget to buy the "; shopping$; "."
```

Running the program might produce the display:

```
What do you need to buy
?"butter, eggs, jam"
Don't forget to buy the butter, eggs, jam.
```

If we did not use the quotation marks when typing the shopping list after the question mark, then the first comma would be taken to mark the end of the string and the rest of the input would be ignored. Another way of dealing with this problem would be to use the INPUT LINE statement which inputs all the characters on a line, including spaces and punctuation.

Exercises

1 Write a program that accepts input of a name and age and displays a birthday greeting.

2 Write a program that accepts input of two singular nouns and two verbs and displays four simple sentences that use these words. For example, given input:

```
dog, cat, chase, hate
```

the program should display:

```
The dog chases the cat.
The dog hates the cat.
The cat chases the dog.
The cat hates the dog.
```

1.6 Using the TAB function

While a program is running, the flashing 'cursor', in the shape of an underline character, marks the point on the screen at which the next character (typed by the user or printed by the computer) will be displayed. We can move the cursor about the screen by using the TAB function in PRINT and INPUT statements.

In MODE 6, there are 40 character positions on a line and these are numbered from 0 to 39. One way of using the TAB function is to indicate where on the current line the computer should start printing the next item. For example, the one line program:

```
10   PRINT TAB(4); "Fred"; TAB(20); "Joe"
```

will display the word "Fred" starting at position 4 on the current line. The word "Joe" is displayed starting at position 20 on the same line.

Thus when we use TAB followed by one number in brackets this moves the text cursor along the current line to the position indicated by the number in brackets. If the cursor

is already past the specified position on the current line, then it moves to that position on the next line.

TAB can also be used with two numbers in brackets where the second number is used to select a line for the cursor to move to. In MODE 6, the screen is divided into 25 lines numbered from 0 (at the top) to 24 (at the bottom). The following program displays a Christmas message in the centre of the screen.

```
10   CLS
20   PRINT TAB(12,9); "Merry  Christmas"
30   PRINT TAB(18,12); "and"
40   PRINT TAB(12,15); "A Happy New Year"
```

In the PRINT statement at line 20, the presence of 'TAB(12,9)' causes the cursor to be moved to character position 12 on line 9 of the screen before the string "Merry Christmas" is printed. The other PRINT statements use TAB in a similar way.

TAB can also be used in an INPUT statement to move the cursor to a new position before the user types the input required by a program. For example, the behaviour of the following program is interesting:

```
10   CLS
20   PRINT TAB(12,10); "Give me a number"
30   INPUT TAB(20,12)  number
40   PRINT TAB(16,12); "2 x "; TAB(15,14); "= "; 2*number
```

You should run this program and make sure that you understand why it behaves as it does. The question mark in the display can be removed by omitting the comma in line 30:

```
30   INPUT TAB(20,12) number
```

In fact lines 20 and 30 could be combined into a single INPUT statement:

```
20   INPUT TAB(12,10), "Give me a number",
          TAB(20,12)  number
```

As a final example of the use of TAB, the following program illustrates how TAB can be used in PRINT statements that display a simple questionnaire on the screen. TAB is then used in INPUT statements to move the cursor around as the user fills in the questionnaire. As it stands, the program does nothing with the information that is input, but one of the exercises below asks you to extend the program.

```
 10   CLS
 20   PRINT TAB(6,1); "Please fill in the following"
 30   PRINT TAB(13,3); "Questionnaire."
 40   PRINT TAB(13,4); "--------------"
 50   PRINT TAB(0,8); "Name:";
 60   PRINT TAB(31); "Age:"
 70   PRINT TAB(0,11); "Address:"
 80   PRINT TAB(0,16); "No. of O-levels:";
 90   PRINT TAB(20); "No. of A-levels:";

100   INPUT TAB(5,8), name$
110   INPUT TAB(35,8), age
120   INPUT TAB(8,11), addline1$
130   INPUT TAB(8,12), addline2$
140   INPUT TAB(8,13), addline3$
150   INPUT TAB(16,16), olevels
160   INPUT TAB(36,16), alevels
```

Note the semicolon at the end of the PRINT statement on line 50. This makes sure that, when the program is being obeyed, the PRINT statement does not start a new line and 'TAB(31)' is all that is needed for the next PRINT statement to print further along the same line. The same thing has been done at line 80.

Exercises

1 Write a program that inputs a message (for example, "Happy Birthday", "Happy Anniversary", etc.) followed by a name and displays a personalised version of the message in the centre of the screen, for example:

```
**********************

      Happy  Birthday

            Jim

**********************
```

2 Write a program that displays a screenful of instructions explaining how to play your favourite arcade game. Use TAB to obtain a visually pleasing layout.

3 Extend the questionnaire program so that it uses the input information to calculate a new employee's salary, where the salary is made up of a basic monthly rate of pay, an increment for each year of the employee's age over 16, an increment for each O-level and an increment for each A-level. The program should display a message welcoming the employee to the company and telling him

what his monthly salary will be.

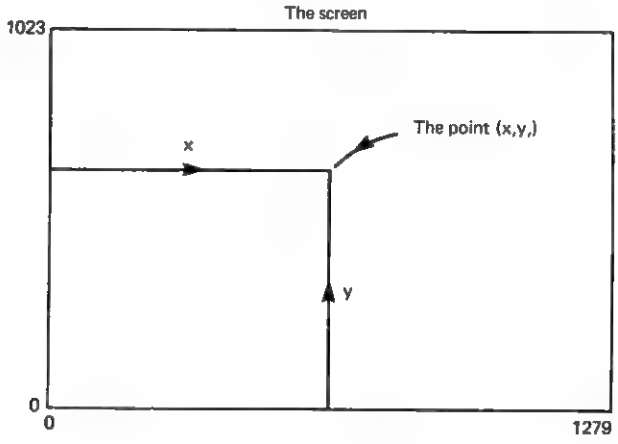
4 Write a program that displays a questionnaire about the day's weather and accepts information typed by the user. Information required might include temperatures at different times of day, rainfall, wind speed, a verbal description of the cloud conditions, and so on. (This program could be part of a more complex program that is used for logging weather records on a daily basis.) Your program should terminate by displaying a few sentences summarising the day's weather conditions.

1.7 Elementary graphics

In the introductory chapter, we saw a simple graphics program that produced a line drawing on the screen by using a combination of MOVE and DRAW statements. Here, we provide some further information on the use of such elementary graphics facilities. Advanced graphics facilities are described in detail in Chapter 9, but it is a good idea to get used to using simple graphics (and sound) facilities as soon as possible rather than considering them advanced facilities to be left until later.

Screen coordinates

We saw in the introductory chapter that a point on the screen is described by giving two values.



The first value indicates the horizontal distance of the point from the left of the screen and the second value indicates the height of the point from the bottom of the

screen. The first value is usually called the x-value or x-coordinate of the point and the second value is usually called the y-value or y-coordinate of the point. For a point on the screen, its x-value is in the range 0 to 1279 and its y-value is in the range 0 to 1023.

Note that when using graphics, vertical distances are measured from the bottom of the screen, whereas the TAB function measures the vertical position of a character from the top of the screen.

The picture drawn by our introductory program was of fixed size. We can obtain more flexible control over the size and shape of the picture drawn by a graphics program by supplying the dimensions required via an INPUT statement. We have done this in the program below which draws a house. Note that lines 100 and 160 of this program are not instructions for the computer to obey. They are 'remarks' whose purpose is to make the program easier to read and understand.

```
 10   PRINT "Dimensions and position of house:"
 20   INPUT "Width", width
 30   INPUT "Height to eaves", height
 40   INPUT "Position: x,y", leftx, bottomy
 50   rightx = leftx + width
 60   eavesy = bottomy + height
 70   roofx = leftx + width/2
 80   roofy = eavesy + height/3

 90   MODE 5

100     REM Draw outline of walls
110   MOVE leftx, eavesy
120   DRAW leftx, bottomy
130   DRAW rightx, bottomy
140   DRAW rightx, eavesy
150   DRAW leftx, eavesy

160     REM Draw outline of roof
170   DRAW roofx, roofy
180   DRAW rightx, eavesy

190   key = GET : MODE 6
```

We have included blank lines in the program to break it up into sections (see Appendix 1).

The statement

```
key = GET
```

at line 190 is very useful when writing graphics programs. Other uses of GET are covered later, but, in this context,

GET makes the computer wait until any key is pressed. The variable 'key' is then given a numeric value that indicates which key has been pressed, although here we do not make any use of this value. Using GET in this way allows the user to look at the picture on the screen and then press any key when he wants the program to switch back to MODE 6.

Drawing accuracy

The edges of the roof drawn by the above program are rather dotted or stepped in appearance. The reasons for such innacuracies are discussed later in Chapter 9. For the time being, you could try changing the MODE statement at line 90 and compare the effects of drawing the picture in different modes. Try

```
90   MODE 4
```

and you should find that the edges of the roof are drawn more accurately. Now try using MODEs 2, 1 and 0. MODEs 2 and 5 provide the same drawing accuracy and MODEs 1 and 4 give the same drawing accuracy. MODE 0 provides the greatest drawing accuracy available.

Drawing in different colours

In MODE 5, drawing can take place in one of four different colours. On first entering MODE 5, the 'background' colour is black and the 'foreground' colour in which drawing takes place is white. The colours normally available in MODE 5 each have a code number:

colour	code number
black	0
red	1
yellow	2
white	3

We can select different colours for drawing by using the GCOL 0 statement. (GCOL stands for Graphics COLour.) For example, if we insert the statement:

```
105   GCOL 0,2
```

in the house drawing program, all the drawing takes place in colour number 2 (yellow). Note that it is the second number in the GCOL statement that selects the colour. For the time being, the first number will always be 0. The significance of this first number will not be discussed until Chapter 9. If we wanted to switch to red before drawing the edges of the roof, we could insert the statement:

```
165   GCOL 0,1
```

The walls will now be drawn in yellow and the roof in red.

In MODE 4, only two colours are available - one for background and one for drawing. These are normally set to black and white.

MODE 0 has only two colours and MODE 1 has the same four colours as MODE 5. MODE 2 has 16 colours, but we shall not present any detailed information about the MODE 2 colours at this stage. We leave you to experiment with them. Each mode provides a different combination of plotting accuracy and colour range.

Exercises

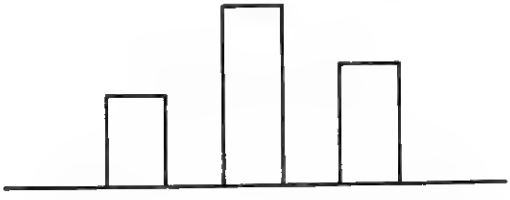
1 Extend the house drawing program so that it draws a door and windows in different colours.

2 The location of the house is specified to our program by giving the coordinates of the bottom left hand corner of the house. Change the program so that the user specifies the position of the centre of the house.

3 Write a program that draws the following car shape:

Use different colours for different parts of the car.

4 Write a program that inputs three numbers and draws the outline of a 'bar chart' or 'histogram' where the heights of the bars show the sizes of the numbers. For example, the bar chart might look like:



Use different colours for the three bars.

5 If you are familiar with equations, write a program that draws a graph of the equation

$$3x + 2y = 1200$$

in MODE 1. Use different colours for the axes and the graph. Use PRINT and TAB to display the equation alongside its graph. Now write a program that inputs values a, b, c and draws a graph of the equation:

$$ax + by = c$$

1.8 Elementary use of sound

If you are not familiar with musical notation, you will have to ignore parts of this section. However, you should still read the rest of it as you may want to use SOUND statements to add sound effects to your programs.

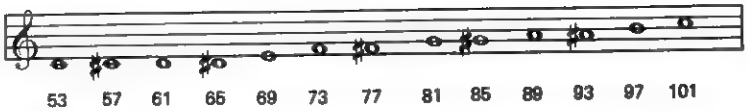
We saw in the introductory section that the SOUND statement is used with four numbers or 'parameters'. The form that a simple sound statement takes can be described as:

```
SOUND channel, loudness, pitch, duration
```

Where the significance of each of the four parameters is:

channel
This parameter is included mainly for compatibility with machines (like the BBC micro) that have more sophisticated sound generators capable of playing notes on several channels simultaneously. The limited use made of this parameter on the Electron will be explained in Chapter 10. For the time being, it will always be set to 1.

loudness
Until we get to Chapter 10, the second parameter of a sound statement will always be negative or zero. It is used to indicate the loudness of the sound that is to be made. A value of -15 gives maximum loudness, -1 gives the quietest sound and 0 gives silence.

pitch
The third parameter indicates the pitch or frequency of the note that is to be played. The pitch is indicated by a code number in the range 0 to 255, where 0 is the code for the lowest obtainable frequency and 255 is the code for the highest obtainable frequency. Pitch number 53 corresponds to Middle C on the piano and an increase of 4 in the pitch code corresponds to raising the pitch by one semitone. Thus, for example, the notes in the octave starting at Middle C have the following pitch codes:

duration
The last parameter indicates how long the sound should last. Its value can be in the range 0 to 255 where this specifies the duration of the sound in twentieths of a second.

Thus the statement

```
10   SOUND 1, -15, 53, 20
```

causes the note Middle C to be played for 1 second. We have already seen that the following program plays three separate notes of a chord starting on Middle C:

```
10   SOUND 1, -15, 53, 20
20   SOUND 1, -15, 69, 20
30   SOUND 1, -15, 81, 20
```

These notes are played consecutively, one after another.

When the computer obeys a SOUND statement, it immediately adds the sound request to a queue. Once this has been done, the sound will be generated independently of the computer and the computer is free to move on to the next statement in the program. We can take advantage of this if we want the computer to do something else while a sound is being played (further details in Chapter 10).

The next program plays the first two bars of a minuet by J. S. Bach.

```
10   SOUND 1, -15, 109, 8
20   SOUND 1, -15, 81, 4
30   SOUND 1, -15, 89, 4
40   SOUND 1, -15, 97, 4
50   SOUND 1, -15, 101, 4
60   SOUND 1, -15, 109, 8
70   SOUND 1, -15, 81, 8
80   SOUND 1, 0, 0, 0
90   SOUND 1, -15, 81, 8
```

The time it takes the sound generator to process the silent note of zero duration at line 80 is just enough to create

the effect of a short gap between two identical notes. Without this statement, the two notes would sound like one continuous note.

Playing a longer piece of music in this way would be rather tedious. We shall see better ways of doing this in later chapters.

Exercises

1 Write a program that plays the scale of C major starting on Middle C.

2 Write a program that plays a few bars of any simple tune.

1.9 READ and DATA statements

It is convenient at this stage to mention an alternative way of supplying information to a program, although we shall not make extensive use of this technique until later. You may like to skip this section on a first reading.

Often a program needs to make use of a set of values that are the same each time the program is run, or which change only occasionally. For example, here is a simple program that calculates the tax to be paid given a standard tax-free allowance, a fixed tax-rate and an annual salary.

```
10   INPUT "Allowance", allowance
20   INPUT "Tax rate (percent)", taxrate
30   INPUT "Salary", salary
40   PRINT "Tax due: "; (salary - allowance)*taxrate/100
```

Each time this program is run, the user must type the standard tax-allowance and tax-rate as well as the annual salary. If the first two values are the same each time the program is used, they should not have to be typed each time that the program is run. Such values should be written into the program in some way.

One way of doing this, that will become more useful when large numbers of values are involved, is to use READ statements to obtain values from DATA statements that are included in the program. A READ statement behaves in much the same way as an INPUT statement but, instead of values being typed when the program is run, the values required by READ are listed in a DATA statement and the computer reads them from there. The above program can be written as

```
10   READ allowance, taxrate
20   INPUT "Salary", salary
30   PRINT "Tax due: "; (salary - allowance)*taxrate/100
40   DATA 2150, 32.5
```

The advantage of this may not be apparent at this early stage. After all, we could have used:

```
10   allowance = 2150  :  taxrate = 32.5
```

However, READ and DATA statements are very useful when we write programs that use large lists or tables of values that are the same each time the programs are run. For example, a program that answers enquiries by finding information in a table might include the table in DATA statements. A program that plays a tune might include DATA statements specifying the pitch and duration of each note to be played.

If a program contains several READ statements, each READ starts reading data at the point where the last READ left off. Thus, the following program:

```
10   DATA 5, 7, 9, 4, 13, 19
20   READ a, b
30   PRINT a + b
40   READ c, d
50   PRINT c + d
60   READ e, f
70   PRINT e + f
```

will print:

```
          12
          13
          32
```

If a program contains several DATA statements, then data is read from them in turn, in the order in which they appear in the program. Thus the program:

```
10   DATA 7, 5
20   DATA 17
30   DATA 4, 9, 13
40   READ a,b,c,d,e,f
50   PRINT a+b, c+d, e+f
```

will print

```
          12          21          22
```

It does not matter where the DATA statements are inserted in the program. However, it is a good idea to keep DATA statements tidily together at the beginning or end of the program.

Finally the RESTORE statement can be used to tell the

program to go back to the start of the DATA. RESTORE followed by a line number tells the program to go back to the start of a particular DATA statement. This facility will be illustrated later when it is needed.

Chapter 2 Doing calculations

In this chapter, we describe in further detail the use of arithmetic expressions and assignment statements for doing calculations. We also introduce the functions that are available in Electron BASIC for doing mathematical calculations. If you are not mathematically inclined, then you can safely skip parts of Section 2.4.

2.1 More about assignment statements

We saw in the last chapter that the result of a calculation can be stored in a variable by an assignment statement such as:

```
100  taxable = income - allowance
```

When this statement is obeyed, the expression on the right is evaluated and its value is stored in the variable whose name appears on the left. In the simplest cases, the right-hand side can be a constant or another variable name. For example:

```
sumsofar = 0
```

stores the value 0 in the variable 'sumsofar'.

```
x = y
```

In this example the contents of 'y' are put into 'x' (the previous contents of 'x' being destroyed or overwritten).

Thus, if before the statement is obeyed we have:

then after the statement is obeyed we have:

Note that the value in 'y' is left unchanged. We do not 'take out' the value in 'y', but 'copy' it into 'x'.

Note that a statement such as:

```
x = x + y
```

which may seem somewhat peculiar, is perfectly valid and means: the value of 'x' becomes equal to what it was before plus the value of 'y'. The right-hand side of an assignment statement is always evaluated first regardless of what variable appears on the left.

Thus if we have:

then immediately after the above statement is obeyed we have:

This idea is used in the following program which illustrates one way of reading and adding two numbers:

```
10   sumsofar = 0
20   INPUT nextnumber
30   sumsofar = sumsofar + nextnumber
40   INPUT nextnumber
50   sumsofar = sumsofar + nextnumber
60   PRINT sumsofar
```

This may seem rather long-winded, but it illustrates a very important point about variables: the value stored in a variable can change while a program is being obeyed. We shall find that the above approach has to be used when large numbers of input values are processed by a program. We shall return to this point in Chapter 4.

2.2 Arithmetic expressions - order of evaluation

In arithmetic expressions used so far, we have sometimes used round brackets. For example, we can write:

```
average = (x + y + z)/3

perimeter = 2*(length + width)
```

In each case we have used the brackets to clarify our intentions. We want the computer to calculate:

$$\frac{x + y + z}{3}$$

so we write:

```
(x + y + z)/3
```

This is simply a consequence of the fact that we are using a keyboard and arithmetic expressions must be typed as a sequence of characters one after another.

If we missed out the brackets:

```
average = x + y + z/3
```

the computer would calculate:

$$x + y + \frac{z}{3}$$

which is not what we intended.

In the other example, if we removed the brackets:

```
perimeter : = 2*length + width
```

the computer would calculate:

```
(2*length) + width
```

You can see from this that the computer has rules for dealing with the evaluation of arithmetic expressions.

Let us begin by listing the operators that have been informally introduced so far, together with one new one:

^	exponentiation
*	multiplication
/	division
+	addition
-	subtraction

The exponentiation operator, '^', is used for raising one number to a power. For example,

```
y = x^3
```

has the same effect as:

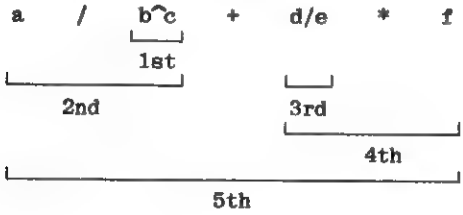
```
y = x*x*x
```

The computer can perform only one of the above operations at a time. To perform an operation it requires two operands, which are the quantities on either side of the operator. In the absence of brackets, exponentiation is carried out before multiplication and division, which are carried out before addition and subtraction.

Consider the expression:

```
a/b^c + d/e*f
```

The computer evaluates this as:



1st result evaluated	b^c
2nd result evaluated	a / 1st result
3rd result evaluated	d/e
4th result evaluated	3rd result * f
5th result evaluated	2nd result + 4th result

Thus the computer evaluates:

$$\frac{a}{b\hat{}c} + \frac{d}{e} * f$$

If instead we wanted the computer to evaluate

$$\frac{a}{b\hat{}c} + \frac{d}{e*f}$$

then we would use brackets:

```
a/b^c + d/(e*f)
```

Anything inside brackets is evaluated first. For the operators introduced so far, we can summarise this order of 'precedence', as it is called:

order of precedence:

1st	anything inside brackets
2nd	exponentiation
3rd	multiplication and division
4th	addition and subtraction

Adjacent operators of the same precedence are applied from left to right.

'Adding' strings

At this point it is appropriate to mention that the operator '+' can be applied to two strings. It adds or 'concatenates' the two strings together to produce one longer string. For example,

```
10   INPUT "first name", firstname$
20   INPUT "surname", surname$
30   fullname$ = firstname$ + " " + surname$
40   PRINT "Your full name is", fullname$
```

2.3 Special integer operators

There are two special arithmetic operators that operate only on integers or whole numbers:

DIV has the same effect as normal division except that any remainder is removed, thus producing an integer result.

MOD supplies the remainder after dividing two integers

DIV and MOD have the same precedence as '*' and '/'. Consider the following examples:

expression	value
16/5	3.2
16 DIV 5	3
16 MOD 5	1
19/5	3.8
19 DIV 5	3
19 MOD 5	4
8 DIV 3 * 3	6
7 + 5 DIV 3	8
13 - 5 MOD 3	11

The use of these operators on negative numbers is rarely useful. If they are applied to real numbers with fractional parts, the fractional parts are removed before the operators are applied. The use of MOD and DIV on anything other than

positive whole numbers is best avoided.

The following program is a supermarket 'checkout' program that prints the number and denomination of coins required to make up a given amount of change (a whole number of pence). The program indicates the number of 50p, 20p, 10p, 5p, 2p, and 1p coins to be paid out.

```
 10   INPUT "Change", change
 15
 20   noof50s = change DIV 50 : change = change MOD 50
 30   noof20s = change DIV 20 : change = change MOD 20
 40   noof10s = change DIV 10 : change = change MOD 10
 50   noof5s  = change DIV 5  : change = change MOD 5
 60   noof2s  = change DIV 2  : change = change MOD 2
 70   noof1s  = change
 75
 80   PRINT "change due is:  no of 50s    "; noof50s
 90   PRINT "                no of 20s    "; noof20s
100   PRINT "                no of 10s    "; noof10s
110   PRINT "                no of  5s    "; noof5s
120   PRINT "                no of  2s    "; noof2s
130   PRINT "                no of  1s    "; noof1s
```

We have now introduced seven arithmetic operators and two of these can be applied only to integer quantities. A complete list of operators is given in Appendix 3.

2.4 Standard mathematical functions

A number of predefined mathematical operations or functions are available for use in expressions. The programs for evaluating these standard functions are built into your BASIC system.

For example

```
10   x = 4
20   PRINT  SQR(x)
```

prints the value 2.

```
10   y = 5.66
20   PRINT INT(y)
```

prints the value 5.

SQR is the name of the standard function which performs the operation 'finding the square root of'. INT is the name of the standard function which finds the 'integer part' of a number, i.e. it removes the fractional part from a real number to give an integer.

When you refer to a function you use its name and enclose

within round brackets the value to which the function is to be applied. This value, which is called a parameter, can be any arithmetic expression. For example,

```
x = SQR(16)
      :
x = SQR(y)
      :
x = SQR(3*y/z)
      :
x = 15.6 + SQR(3*y/z)
      :
```

Because parameters can be arithmetic expressions, a function can be used in the expression which is the parameter of another function:

```
PRINT INT(SQR(17.3))
```

prints 4.

```
PRINT SQR(SQR(16))
```

prints 2.

```
theta = PI/3
PRINT SQR(SIN(theta) + COS(theta))
```

prints 1.16877089.

You should note that while people usually work in degrees, the parameters of trigonometric functions in BASIC have to be given in radians. The 'predefined constant' PI used above has a value of 3.14159265. A function RAD is available for converting degrees into radians, and its use is illustrated in the next program. For a standard 'inverted v' shaped roof, this program works out the area of roof covering required, given the angular pitch of the roof and the length and width of the building.

```
10   INPUT "Pitch of roof(degrees)", pitch
20   INPUT "Length and width", length, width
25
30   pitch = RAD(pitch)
40   areaofroof = width/COS(pitch) * length
45
50   PRINT "Area of roof covering required is ";
            areaofroof; " sq.m."
```

The following program draws a triangle given the length of the base and the two base angles (in degrees).

```
10   INPUT "Base", base
20   INPUT "Base angles", a1, a2
30   tana1 = TAN(RAD(a1)) : tana2 = TAN(RAD(a2))
40   height = base/(1/tana1 + 1/tana2)
50   topx = height/tana1

60   MODE 4
70   DRAW topx,height
80   DRAW base,0
90   DRAW 0,0
100  key = GET  :  MODE 6
```

Note that without a MOVE statement, drawing starts from the bottom left hand corner of the screen, the point (0,0).

The function INT mentioned above converts a real number into the whole number that is 'less than or equal' to it. If we want to convert a real number, x say, into the 'nearest' integer, we can use the expression:

```
INT(x+0.5)
```

This trick is used in the following program which converts degrees Centigrade to degrees Fahrenheit.

```
10   INPUT "Temperature(centigrade)", cdegrees
20   fdegrees = cdegrees * 9/5 + 32
30   PRINT cdegrees; "C = "; fdegrees; "F or approx ";
                             INT(fdegrees + 0.5); "F"
```

This will produce a display such as:

```
Temperature(centigrade)?21.5
21.5C = 70.7F or approx 71F
```

The following program demonstrates how the function INT can be used to convert a time expressed as a real number of hours into hours and minutes (to the nearest minute). Given a distance between two towns, a speed in miles per hour and a departure time from one town, the program prints the arrival time at the other town. Times are input as, for example, 0845 or 1357 and are output as, for example, 8-45 and 13-57. We assume that the journey takes place in one day.

```
10   INPUT "Distance",distance, "mph",mph,
                          "Start time",startime
20   hours    = startime DIV 100
30   mins     = startime MOD 100
40   realhours= hours + mins/60
```

```
 50      REM next statement calculates time of arrival
 60      REM as a real number of hours after midnight

 70   realhours = realhours + distance/mph

 80      REM now convert time back into hours and mins

 90   hours     = INT(realhours)
100   mins      = INT((realhours - hours)*60 + 0.5)
110   PRINT "Arrival time: "; hours; "-"; mins
```

There is a complete list of standard functions in Appendix 9.

Exercises

1 A pay rise of 9.9 per cent has been awarded to a company's employees. Write a program to which an employee can supply as input his previous annual salary and which will inform him of his new annual, monthly and weekly rates of pay. (Assume that there are exactly 52 weeks in the year.)

2 Write a program that inputs a length in inches and prints the corresponding length in feet and inches, and then in metres and centimetres (to the nearest centimetre). (1foot = 0.3048 metres)

3 A retiring employee is entitled to an annual pension of one fiftieth of his current annual salary for each complete year's service with the company. All employees start work on the first day of a month and retire on the last day of a month. Write a program into which an employee can type his current annual salary, the month and year he started work with the company and the month and year he retired. A month can be supplied as an integer in the range 1 to 12 The program should inform him what his annual pension will be. HINT: Calculate the total number of months worked and then use DIV to calculate the number of complete years.

4 Write a program that accepts as input the amount of cash (a real number of pounds) to be enclosed in an employee's pay packet. The program should do a 'coin and note analysis' and print the number of coins and notes, of each available denomination, that are to be included in the pay packet.

5 Write a program that calculates the height of a tree, given the distance of a point from the foot of the tree and the angle the top of the tree makes with the

horizontal when viewed from this point.

6 Extend the previous program so that it draws a diagram illustrating the situation.

7 Given a departure and arrival time based on the 24 hour clock write a program that will print out the duration of the journey (assumed to take place all in one day).

2.5 Inventing random numbers: the function RND

Many computer programs are improved if a random element is incorporated in their behaviour. For example, a game playing program should exhibit some degree of unpredictability in its behaviour. A computer assisted learning program should present the user with unpredictable questions. Some interesting graphics effects can be created by programs that incorporate some randomness in their behaviour.

To make the computer invent random numbers, we use the function RND. There are two ways in which we shall use this function. The first method is used for inventing random integers. If n is an integer greater than 1, then RND(n) has a value that is a random integer in the range 1 to n. Thus the following program displays 3 random multiplication questions where each number involved is in the range 1 to 12:

```
10   PRINT RND(12); " x "; RND(12); " ="
20   PRINT RND(12); " x "; RND(12); " ="
30   PRINT RND(12); " x "; RND(12); " ="
```

We shall see in a later chapter how to input answers and test them to see if they are correct. It would be sensible to stop the program printing questions involving 1, such as:

```
1 x 4 =
6 x 1 =
1 x 1 =
```

To do this we need to generate random numbers in the range 2 to 12. This can be done as follows:

```
10   PRINT RND(11) + 1; " x "; RND(11) + 1; " ="
```

Inventing a number in the range 1 to 11 and adding 1 to it gives a number in the range 2 to 12. A similar trick is used in the following program which displays 5 random lines on the screen, each line being in a random colour. To generate a number in the range 0 to 1279, we subtract 1 from a number in the range 1 to 1280.

```
 10   MODE 5
 20   GCOL 0, RND(3)
 30   DRAW RND(1280)-1, RND(1024)-1
 40   GCOL 0, RND(3)
 50   DRAW RND(1280)-1, RND(1024)-1
 60   GCOL 0, RND(3)
 70   DRAW RND(1280)-1, RND(1024)-1
 80   GCOL 0, RND(3)
 90   DRAW RND(1280)-1, RND(1024)-1
100   GCOL 0, RND(3)
110   DRAW RND(1280)-1, RND(1024)-1
```

The other type of random number that we shall occasionally use is a random real number in the range 0 to 0.9999999. Such a number is produced by using RND with a parameter 1. For example:

```
10   PRINT RND(1)
```

prints a different real number in this range each time it is run.

Exercises

1 Write a program that displays a list of 5 random addition questions where the numbers involved all lie in the range 1 to 100. Change the program so that the numbers produced all lie in the range 10 to 100.

2 Write a program that plays a sequence of 3 notes, each of random pitch and random duration.

Chapter 3 Choosing alternatives

Up to now we have seen that a computer program is a list of statements obeyed one after the other. In this chapter we will be looking at how we tell the computer to select particular statements for execution and to ignore others. We build into the program various alternative courses of action or pathways and the computer steers a particular course through the program depending on the outcome of tests that it makes as it proceeds.

Most practical programs have such facilities built into them somewhere. This is another way in which programs achieve generality and flexibility. A program issuing car insurance for example would have various alternative courses of action which would depend upon the applicant's age, any previous claims or convictions and class of car. A program controlling an industrial process may issue different control signals depending on input data. 'Increase the gas supply to a burner if the temperature in an oven is low, decrease it if it is high' is a simple and common example.

3.1 IF-THEN statements

The simplest BASIC statement involving selection of alternative courses of action is do-don't selection, i.e. the computer executes or ignores a statement depending on the outcome of a test. Consider the following simple examples:

```
IF prevcon > 3 THEN fine = fine*2
```

(The value of 'fine' is doubled if the value of 'prevcon' is greater than 3 otherwise it is left unchanged)

```
IF total > 100 THEN total = total - 0.10*total
```

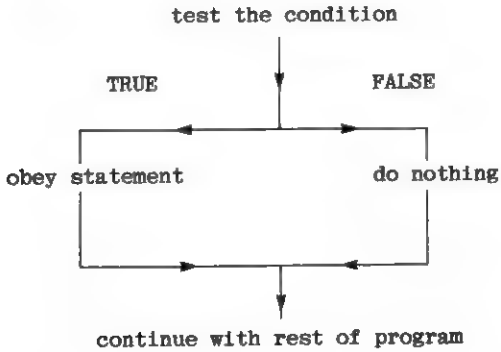
(The value of 'total' is reduced by 10 percent providing it is greater than 100 - a discount facility)

```
IF weight > 200 THEN PRINT "try slimming"
```

(A message is either printed or not)

In each of these examples the form is:

and the behaviour of such simple IF-THEN statements can be illustrated:



The branch taken depends on the outcome of the test. If the condition is satisfied then the left hand branch is followed, otherwise the right hand branch is taken. We say that the outcome of a test is the value TRUE or the value FALSE and this is a concept of which we shall make frequent use later. A simple condition relates two quantities using one of a number of relational operators. The particular relational operator we used above was '>' which means 'greater than'.

The complete list of relational operators is:

operator	meaning
>	greater than
>=	greater than or equal to
<	less than
<=	less than or equal to
=	equal to
<>	not equal to

The operators >=, <= and <> are single operators written as two characters because of the limited number of characters usually available on a keyboard.

The following examples use these operators:

```
IF age >= 18 THEN PRINT "elig. for jury service"

IF x <> y THEN PRINT "x and y are unequal"
```

The above are all examples of do-don't selection, the computer executes a statement or does nothing depending on the outcome of a test.

The input to the next program is a price or total. This is to be reduced by 10 per cent if it is greater than or equal to 100.

```
10   PRINT "type in total"
20   INPUT tot
30   IF tot >= 100 THEN tot = tot - 0.10*tot
40   PRINT "Total is now "; tot
```

There are two points to note in this program. Firstly it is your responsibility to remember in which cash units you are working - the computer manipulates the numeric value of 'tot'. It has no knowledge as to whether the value represents dollars, pounds or zlotys. Secondly line 40 will display either the value of 'tot' as input, or an adjusted value.

Here is a program that makes up two random integers in the range 1 to 100 and asks the person seated at the keyboard to add them together. If the wrong answer is typed, the program plays a low-pitched note.

```
10   a = RND(100) : b = RND(100)
20   PRINT a; "+"; b; "=";
30   INPUT answer

40   IF a + b <> answer THEN  SOUND 1,-15,0,50
```

Exercises

1 Write a program that takes as input two amounts representing the current balance of a bank account and a withdrawal. The program is to display the new balance together with a warning if the account 'goes into the red'.

2 Experiment with the SOUND statement used at the end of the last section so as to vary the sound produced.

3.2 IF-THEN-ELSE statements

Now consider the following examples:

```
IF age >= 18 THEN PRINT "elig " ELSE PRINT "underage"

IF age > 20 THEN bonus = pay*0.2 ELSE bonus = pay*0.1
```

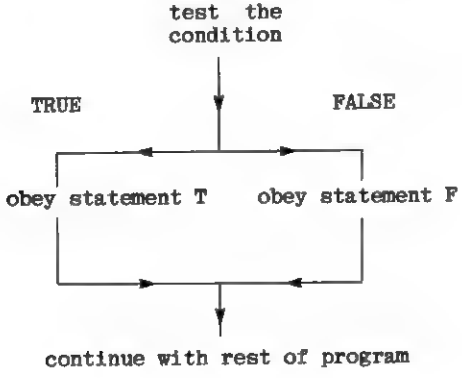
These examples illustrate 'do one or the other' selection. The computer executes the statement following the THEN if the test is TRUE, otherwise (or ELSE) it executes the other. Incidentally, especially when using mnemonic names, an IF-THEN-ELSE statement may not fit on one screen line. However the program line may be broken over several lines on the screen as described in Section 1.3.

```
40    IF answer = a + b THEN
          PRINT "That's right!"
      ELSE SOUND 1,-15,0,50
```

The whole statement must be typed without pressing the RETURN key, extra spaces being used to take us onto the next line where necessary. Remember that a BASIC statement can not occupy more than 6 screen lines in MODE 6.

The form for a simple IF-THEN-ELSE statement is:

Its behaviour can be illustrated:



Again we are selecting one out of two alternatives but this time the second alternative, instead of being to do nothing,

is another statement. Again the selection is dependent on the outcome of the test which can be either TRUE or FALSE. 'Statement T' is executed if (the value of) the condition is TRUE, otherwise 'statement F' is executed because (the value of) the condition is FALSE. Here are some programs illustrating these facilities.

This discount program is like the previous except that if the total is less than 100 it is reduced by 5 per cent instead of being left unaltered.

```
10   PRINT "type in total"
20   INPUT tot
30   IF tot >= 100 THEN tot = tot - 0.10*tot
                   ELSE tot = tot - 0.05*tot
40   PRINT "After discount, total is "; tot
```

The next program uses two IF-THEN-ELSE statements. It takes as input 3 numbers and displays the largest of these three numbers.

```
10   PRINT "Type in 3 numbers"
20   INPUT n1, n2, n3
30   IF n1 > n2 THEN maxsofar = n1
                ELSE maxsofar = n2
40   IF maxsofar > n3 THEN PRINT maxsofar
                      ELSE PRINT n3
```

The first IF-THEN-ELSE statement puts the larger of the first two numbers into 'maxsofar'. The second IF-THEN-ELSE compares the larger of the first two numbers (now in 'maxsofar') with the third.

This program illustrates the classical limitation of computers and one of the reasons why programming is something of a skill. Here we have a very simple logical task 'find the largest of 3 numbers'. Because the computer can only perform one calculation or one comparison at any one time we have to break the problem down into 2 pairwise comparisons. The computer is a sequential machine and even apparently simple tasks like this have to be broken down into a sequence of fundamental calculations. It is this breaking down of a task, easily specified in English, into a sequence of fundamental steps, not so easily specified in a computer language, which is really what programming is all about.

Exercises

1 Write a program that displays an addition question and makes one sound if an answer typed at the keyboard is

correct and a different sound if the answer is wrong. Experiment with the SOUND statement until you find two appropriate sounds.

2 Write a program to print an electricity bill given a present and previous meter reading. The program should take account of the fact that a meter goes back to zero after reaching 99999, making the previous reading greater than the present.

3 Write a program to accept two items of information: a British shoe size and a 1 or 0 to indicate a man's or woman's shoe. The program is to output the American size according to the table:

Men's shoes						
British	7	8	9	10	11	
American	7.5	8.5	9.5	10.5	11.5	(ie. add 0.5)

Women's shoes						
British	3	4	5	6	7	
American	4.5	5.5	6.5	7.5	8.5	(ie. add 1.5)

4 Write a program that accepts four examination marks and prints out a 'pass/fail' message depending on whether the average is greater than or equal to 50, or less than 50.

3.3 Comparing strings

The next program is identical to the previous one except that the numeric variables have been changed to string variables. The input to the program is three names. The program carries out exactly the same operations as the previous one, but on strings instead of numbers.

```
10   PRINT "Type in 3 names"
20   INPUT n1$, n2$, n3$

30   IF n1$ > n2$ THEN maxsofar$ = n1$
                  ELSE maxsofar$ = n2$

40   IF maxsofar$ > n3$ THEN PRINT maxsofar$
                        ELSE PRINT n3$
```

If you execute this program and type in 3 names, in capital letters, you will find that it prints the name that comes last alphabetically. When comparing strings, the operator '>' is best read as 'comes after alphabetically'.

Computers usually store letters using a code that increases in unit steps. In the case of capital letters the

lowest code represents "A" and the highest code represents "Z". Therefore, as far as computers are concerned, the 'highest' capital letter in the alphabet is "Z" and the 'lowest' is "A". When the computer is comparing names it compares on the basis of the first character in each name. Thus, "JOHN" comes after "ALAN" because "J" is further on in the alphabet than "A". If the first character in each name is the same, then it compares on the basis of the second characters, and if they are the same, then it compares on the basis of the third etc. Thus "HEART" comes after "HEARS".

A similar ordering applies to the lower case letters. Thus "a" comes before "b" which comes before "c" and so on. However, all the capital letters come before the lower case letters, so that "A", "B", ..., "Z" all come before "a". This means that you must be careful if you want to compare words, some of which start with a capital letter and some of which start with a small letter. All the relational operators that are used to compare numeric entities can be used in the context of strings. You should be able to work out their effect on strings.

The following program tests two strings for equality. It tests whether someone seated at the keyboard knows who wrote 'War and Peace'.

```
10   PRINT "Who wrote WAR AND PEACE";
20   INPUT answer$
30   IF answer$ = "Tolstoy" THEN PRINT "Correct!"
                            ELSE PRINT "Rubbish!"
```

The answer has to be typed exactly as the program expects it. "L. Tolstoy" or "Leo Tolstoy" will not be accepted. More advanced string comparison facilities will be discussed later in Chapter 8.

Manipulations on strings are often used in commercial programming: for example, sorting a list of names into alphabetical order for insertion in a telephone directory or sorting a list of names and addresses according to cities.

Exercises

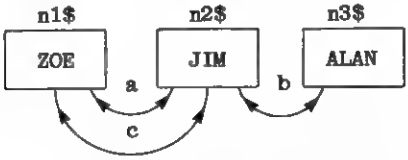
1 Write a program to process a banking transaction. The input is to consist of 3 items of information: a balance, an amount, and, the character "c" or "d" depending on whether the amount is a credit or a debit. The program is to print out the new balance.

2 Change the first program of the last section so that it selects and prints the name that comes first alphabetically. Now extend the program so that it accepts input of four names and prints the one that comes first

alphabetically.

3.4 Compound statements

So far we have looked at 'do-do nothing' conditional statements and 'do one or the other' conditional statements. In each case the thing that was obeyed or ignored was a single statement. Suppose we have a context where more than one statement is to be obeyed conditionally. For example what if we wanted to sort a set of 3 names into alphabetical order? We could do this as follows: Say we have the 3 names in 'n1$', 'n2$' and 'n3$' and we want to end up with the 'first alphabetically' in 'n1$' and the 'last alphabetically' in 'n3$'. Remember that in computer programs we can only perform manipulations like comparisons between two entities one at a time. To get the names into alphabetic order we compare 'n1$' and 'n2$', and if they are in the wrong order, swap their contents over. We perform the same operation with 'n2$' and 'n3$', and then with 'n1$' and 'n2$' again. This will guarantee that the names end up in alphabetic order. Try it on a bit of paper.




```
a    :    1st conditional swap
b    :    2nd   "          "
c    :    3rd   "          "
```

We could summarise the program as:

```
IF  n1$  > n2$  THEN swap them
IF  n2$  > n3$  THEN swap them
IF  n1$  > n2$  THEN swap them
```

Now the point about this example is that we need three BASIC statements to swap the contents of 2 variables:

```
temp$  = n1$
n1$    = n2$
n2$    = temp$
```

swaps the contents of n1$ and n2$. You may have thought that two statements such as:

```
n1$ = n2$
n2$ = n1$
```

would suffice, but if you try this out on a piece of paper you will find that you end up with identical contents in each variable! So given that we now have 3 statements to be conditionally obeyed or associated with each IF statement we need a way of tying these 3 statements together - making them behave as a single statement. We do this by using colons:

```
10   IF n1$ > n2$ THEN temp$ = n1$:
                       n1$ = n2$:
                       n2$ = temp$
```

The effect of using colons is to make the three statements behave as one:

```
10   IF n1$ > n2$ THEN  obey 3 statements
                        as if they were
                        a single statement
```

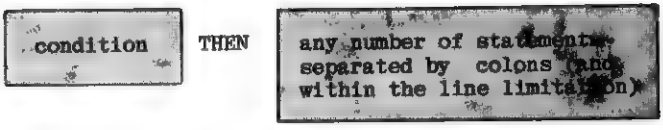
Note that the restriction of 6 screen lines per statement applies to the complete IF-THEN statement including all the statements listed after the THEN. In more sophisticated languages a grouping of several statements into one is known as a 'compound statement'. As far as the IF statement is concerned the three statements are treated as if they were a single 'compound statement'.

Here is a complete program for sorting three names into alphabetic order.

```
10   PRINT "Type in 3 names"
20   INPUT n1$, n2$, n3$

30   IF n1$ > n2$ THEN  temp$ = n1$:
                        n1$ = n2$:
                        n2$ = temp$

40   IF n2$ > n3$ THEN  temp$ = n2$:
                        n2$ = n3$:
                        n3$ = temp$

50   IF n1$ > n2$ THEN  temp$ = n1$:
                        n1$ = n2$:
                        n2$ = temp$

60   PRINT "Sorted names are" ' n1$, n2$, n3$
```

This program serves as an illustration of compound statements; realistic techniques for sorting large numbers of names into order are mentioned in Chapter 6. Of course you need not use as extravagant a program layout as this; we have used such a layout to make clear the meaning of the program.

The general form of an IF-THEN with a compound statement is thus:



We have already mentioned that, even if we are not using an IF-statement, we can use colons to group several statements together on one line:

```
10   INPUT a, b
20   sum = a + b : diff = a-b : prod = a*b
30   PRINT sum, diff, prod
```

The same facility can be used with an IF-THEN-ELSE statement and the next programs illustrate this.

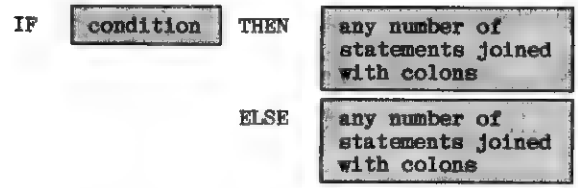
Here is a program that processes a bank account using different interest rates depending on whether the account is overdrawn or not. Also it prints a message suggesting either an overdrawn letter or a statement.

```
10   INPUT balance
20   IF balance < 0 THEN
         PRINT "Write overdrawn letter" :
         balance = balance + 0.025*balance
     ELSE
        PRINT "Send statement" :
        balance = balance + 0.018*balance
30   PRINT "Balance is now "; balance
```

The next program draws a square or a triangle as specified by someone at the keyboard.

```
10   INPUT "square or triangle", shape$
20   MODE 1
30   MOVE 400,400
40   DRAW 800,400          :REM draws the base line.

50   IF shape$ = "square" THEN  DRAW 800,800 :
                                DRAW 400,800 :
                                DRAW 400,400
                           ELSE DRAW 600,800 :
                                DRAW 400,400
60   keypressed$ = GET$    :REM wait until key pressed.
70   MODE 6
```

The general form is:



A more widely available BASIC statement used for obtaining the above effect is the GOTO statement (see later). The above method is more elegant and results in considerably more readable programs. Even when forced to use GOTO statements, it is still helpful to plan a program in terms of IF-THEN or IF-THEN-ELSE statements.

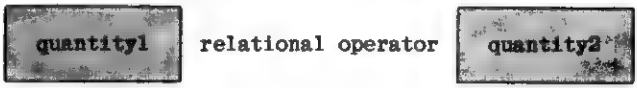
Exercises

1 Write a program that finds the sum and difference of two numbers, first ensuring that the larger of the two numbers is in the variable 'larger' and the smaller is in the variable 'smaller'.

2 Extend the 'square or triangle' program so that the user specifies the colour to be used (red or yellow) in drawing the shape.

3.5 More complicated conditions

The simple conditions we have used so far have been composed of two quantities related by a relational operator:



The quantities we have used have been variables but they can also be arithmetic expressions:

```
IF  sum1 + sum2 - credit > 250 THEN
    PRINT "Credit limit exceeded"


IF age - 60 < 5 THEN
   benefit = lumpsum * 1.5
ELSE
   benefit = lumpsum


IF total > 1.5 * currentbalance THEN
   PRINT "Credit limit exeeded."
```

We can combine more than one condition in an IF statement by joining conditions together using the words AND and OR:

```
IF previousconvictions > 3 AND timespread < 1.5 THEN
   fine = fine * 4


IF weight > 200 AND height < 1.7 THEN
   PRINT "you are overweight"
ELSE
   PRINT "your weight is reasonable"


IF weight > 200 OR dailycalories > 2000 THEN
   PRINT "cut down"
ELSE
   PRINT "ok"


IF x = y AND x > 0 AND y > 0 THEN
   PRINT "x and y are equal and positive"
```

Remember that each complete IF-THEN or IF-THEN-ELSE statement represents a single numbered line of BASIC program even where it occupies several screen lines. The words AND and OR join individual conditions together to make a more complicated condition. Technically, a condition is called a logical expression.

A common mistake made by new programmers is to write:

```
IF x > 0 AND < 10 THEN ...
```

instead of:

```
IF x > 0 AND x < 10 THEN ...
```

You should see from this that each constituent simple condition involving a relational operator must be complete.

The operators AND and OR are universally available in all high level languages. Electron BASIC allows another logical operator EOR, the mnemonic for 'exclusive or'. To appreciate the difference between EOR and OR try running a small program that includes:

```
IF weight > 200 EOR dailycalories > 2000 THEN
   PRINT "cut down"
```

and note the difference in effect between using the EOR and OR operators. The OR operator includes the case when both relational expressions are TRUE, whereas the EOR operator excludes this case. In the context of this example the use of the OR is correct. The use of EOR is clearly erroneous. In practice, you will find that the EOR operator is very rarely needed.

3.6 Things you need to know about AND, OR (and EOR)

When an IF statement contains a condition involving AND and OR, the meaning of the condition is usually clear from reading the program. However, here we tabulate the possible values of a composite condition involving two subsidiary conditions.

IF condition1 AND condition2 THEN.....

condition1	condition2	composite condition
FALSE	FALSE	FALSE
FALSE	TRUE	FALSE
TRUE	FALSE	FALSE
TRUE	TRUE	TRUE

IF condition1 OR condition2 THEN.....

condition1	condition2	composite condition
FALSE	FALSE	FALSE
FALSE	TRUE	TRUE
TRUE	FALSE	TRUE
TRUE	TRUE	TRUE

IF condition1 EOR condition2 THEN.....

condition1	condition2	composite condition
FALSE	FALSE	FALSE
FALSE	TRUE	TRUE
TRUE	FALSE	TRUE
TRUE	TRUE	FALSE

Try making up your own examples using combinations of AND, OR and EOR. The words AND, OR and EOR are called logical operators and they join conditions or logical expressions together, just as arithmetic operators join arithmetic expressions together.

The other logical operator we use is NOT. Its use can be illustrated by a simple example:

```
IF NOT (x = y) THEN
   PRINT " x and y are unequal"
```

is exactly equivalent to:

```
IF x <> y THEN
   PRINT " x and y are unequal"
```

As with arithmetic operators, there is an order of priority for logical operators. The order of priority is NOT, AND, OR(or EOR). Thus:

```
IF calories>2000 OR weight>200 AND height<1.7 THEN ...
```

is equivalent to:

```
IF calories>2000 OR (weight>200 AND height<1.7) THEN ...
```

and not to:

```
IF (calories>2000 OR weight>200) AND height<1.7 THEN ...
```

Remember: if in doubt, you can use extra brackets to make your intentions clear. The use of redundant brackets can often help to make a complicated condition more readable.

There is in fact an overall order of precedence defined for the complete set of Electron BASIC operators (see Appendix 3).

Exercises

1 An insurance policy is to be issued only if the applicant is over 18, has a car with an engine size under 2000cc and has less than 3 motoring convictions. Write a program that inputs the relevant information and states whether

or not a policy is to be issued.

2 Extend the last example so that if the policy is refused a reason is given.

3.7 Logical variables

Up to now we have stored integer and real numbers in variables. You can also store the values TRUE or FALSE in a numeric variable. (These values are in fact represented inside the computer by numbers.) Although this is not a strictly necessary facility it can be used to make programs easier to read. The use of such a logical variable is illustrated in the next fragment which prints out part of a menu. The dishes on the menu are to vary according to whether or not it is a summer month.

```
10   INPUT month
20   itsasummermonth = (month >= 5 AND month <= 8)

30   IF itsasummermonth THEN PRINT "Melon"
                        ELSE PRINT "Oysters"

40   PRINT "Roast chicken with ";
50   IF itsasummermonth THEN PRINT "green salad"
                        ELSE PRINT "two veg"
```

When the program is being obeyed, the value of the condition:

```
month >= 5 AND month <=8
```

is TRUE or FALSE. This value (actually -1 or 0) is stored in the variable 'itsasummermonth'. Apart from the program being easier to read and develop, it can refer to the value of the condition as often as is necessary without having to perform the test again. The brackets in line 20 are not strictly necessary, but they make the statement easier to read. The next fragment uses logical variables together with the operator NOT.

```
10   INPUT height, weight
20   tall = height > 1.8
30   heavy = weight > 200

40   IF tall AND heavy THEN
        PRINT "You are big enough to be a policeman"
50   IF NOT tall AND NOT heavy THEN
        PRINT "Have you thought about being a jockey?"
```

The next program would involve considerable testing if the logical variables were not used.

An insurance broker wishes to implement the following guidance table in a program, so that when he types in an age, engine capacity, and number of convictions the appropriate message is displayed.

age	engine size	convictions	message
>=21	>=2000	>=3	policy loaded by 45%
>=21	>=2000	< 3	policy loaded by 15%
>=21	< 2000	>=3	policy loaded by 30%
>=21	< 2000	< 3	no loading
< 21	>=2000	>=3	no policy to be issued
< 21	>=2000	< 3	policy loaded by 60%
< 21	< 2000	>=3	policy loaded by 50%
< 21	< 2000	< 3	policy loaded by 10%

```
 10 INPUT age, cc, convictions
 20 over21  = age >= 21
 30 largecar = cc >= 2000
 40 riskdriver = convictions >= 3

 50 IF over21     AND     largecar AND     riskdriver
    THEN PRINT "Policy loaded by 45 percent"

 60 IF over21     AND     largecar AND NOT riskdriver
    THEN PRINT "Policy loaded by 15 percent"

 70 IF over21     AND NOT largecar AND     riskdriver
    THEN PRINT "Policy loaded by 30 percent"

 80 IF over21     AND NOT largecar AND NOT riskdriver
    THEN PRINT "No loading"

 90 IF NOT over21 AND     largecar AND     riskdriver
    THEN PRINT "No policy to be issued"

100 IF NOT over21 AND     largecar AND NOT riskdriver
    THEN PRINT "Policy loaded by 60 percent"

110 IF NOT over21 AND NOT largecar AND     riskdriver
    THEN PRINT "Policy loaded by 50 percent"

120 IF NOT over21 AND NOT largecar AND NOT riskdriver
    THEN PRINT "Policy loaded by 10 percent")
```

3.8 The GOTO statement

In this very brief section, we mention what must be one of the most widely used (and abused) statements in the BASIC language - the GOTO statement. This statement is used to tell the computer to transfer its attention to a different line of the program. For example:

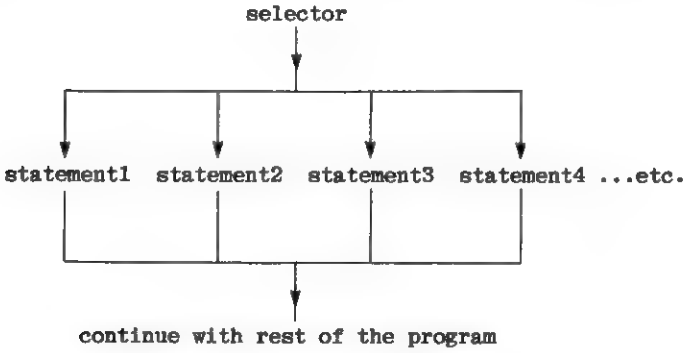
```
50    GOTO 120
```

tells the computer to obey the statement at line number 120 next and carry on from there. We shall use this statement only when it is absolutely essential (for example, in the next section). Electron BASIC provides other language constructions that cover the vast majority of programming situations - USE THEM!

Although the GOTO statement looks deceptively simple, excessive use of GOTO statements leads to programs whose possible execution pathways are so intertwined that they are difficult to read, difficult to debug and difficult to modify.

3.9 Selecting one of many alternatives - ON-GOTO

There are many contexts in which we require a statement to select one out of a number of alternatives, rather than one out of two alternatives. One way of doing this can be represented diagrammatically as:



We have replaced a condition which could have one of two values - TRUE or FALSE - with a more general selector. The two-valued condition which selected one out of two branches has been replaced by an entity which can select one out of a number of branches.

Consider the following program fragment that converts a

date typed in as, for example:

```
3, 2
```

into

```
3 February is the date.
```

```
  1   INPUT day, month
  2   PRINT day;
  3   ON month GOTO  10, 20, 30, 40, 50, 60,
                     70, 80, 90, 100, 110, 120

 10       PRINT " January"  ; : GOTO 130
 20       PRINT " February" ; : GOTO 130
 30       PRINT " March"    ; : GOTO 130
 40       PRINT " April"    ; : GOTO 130
 50       PRINT " May"      ; : GOTO 130
 60       PRINT " June"     ; : GOTO 130
 70       PRINT " July"     ; : GOTO 130
 80       PRINT " August"   ; : GOTO 130
 90       PRINT " September"; : GOTO 130
100       PRINT " October"  ; : GOTO 130
110       PRINT " November" ; : GOTO 130
120       PRINT " December" ;

130   PRINT " is the date."
```

The effect of the ON-GOTO statement should be fairly obvious. Line 3 causes the program to select one out of the lines 10 to 120 depending on the value in 'month'. We shall call the variable 'month' the selector. The effect of the ON-GOTO statement is to cause the program to select the n'th statement number in the GOTO list, where n is the value of the selector. What happens if the selector contains a number that is greater than the number of items in the GOTO list? In this event an execution error will occur. It is always good programming practice to prevent execution errors and make the program print an error message. If a program error message is printed rather than an operating system message, then it can always be specific to the program context. This will always be easier for a user of the program to understand and interpret. In this case prevention of an execution error can be achieved by using an ON-GOTO-ELSE statement. Line 3 would then be:

```
3   ON month GOTO 10, 20, 30, 40, 50, 60,
                  70, 80, 90, 100, 110, 120
    ELSE PRINT " You have typed an erroneous month" :
         PRINT " Please rerun the program" :  END
```

Now the proliferation of 'GOTO 130's in the above example may seem a bit clumsy, but in fact they are not redundant. Without a 'GOTO 130', the program would carry on and obey the statement immediately after the one selected. After a particular statement is selected, a GOTO can transfer control to anywhere in the program, i.e. all the GOTOs could specify different destinations. This is not, however, recommended practice - the ON-GOTO then becomes a sort of complicated junction where the program control goes in through a single entrance and out through one of several different exits. As we have already stated, this sort of thing makes a program very difficult to read, debug or modify.

3.10 Tricks with the ON-GOTO statement

Although the ON-GOTO statement in BASIC is rather restrictive compared with the equivalent facility in more sophisticated languages, it can be enhanced by using various tricks. For example consider the following:

```
1   INPUT month
2   ON month GOTO 10, 10, 20, 20, 20,
                  30, 30, 30, 30,
                  20, 10, 10

10      PRINT "low season rate"    : GOTO 40
20      PRINT "mid season rate"    : GOTO 40
30      PRINT "peak season rate"
40      .
        .
```

This may be part of a holiday booking program. A month is input to the program and the program displays one out of 3 messages. Here we have only 3 statements but the selector can take 1 out of 12 values. The equivalence between the 12 values in the selector and the 3 statements is achieved by duplicating the appropriate line numbers in the ON-GOTO statement.

The next program uses an arithmetic trick to select one out of 4 interest rates.

The yearly rate of interest on a loan is:

```
   0 <  loan < 1000  -  10 %
1000 <= loan < 2000  -  11 %
2000 <= loan < 3000  -  11.5 %
3000 <= loan < 4000  -  11.75 %
4000 <= loan < 5000  -  12 %
```

The program works out a year's interest given the size of the loan. Note that the interest rate could not be conveniently calculated using a single expression because the variation of rate with loan size is not linear.

```
10   INPUT loan
20   ON (INT(loan/1000) + 1)  GOTO 21, 22, 23, 24, 25

21     intrate = 10    : GOTO 30
22     intrate = 11    : GOTO 30
23     intrate = 11.5  : GOTO 30
24     intrate = 11.75 : GOTO 30
25     intrate = 12

30   PRINT " Interest to pay "; loan*intrate/100
```

Finally if the value that is to be used to select a statement is not a small integer, and can not be easily converted into one, a construction like the following might be useful:

```
 5    INPUT m$
10      IF m$="Jan"  THEN
          PRINT "January"   : GOTO 130
20      IF m$="Feb"  THEN
          PRINT "February"  : GOTO 130
30      IF m$="Mar" THEN
          PRINT "March"     : GOTO 130
        :
        :
120     IF m$="Dec" THEN
          PRINT "December"
130     :
        :
```

The selector is tested against each possible value that it could take. With this construction, the GOTO statements could be omitted. If efficiency is a consideration, the use of the GOTOs stops the program wasting time testing the selector against other values when a match has been found. This construction, especially without the GOTOs, is rather more readable than the others and we shall tend to use it even where an ON-GOTO would have been appropriate. Program

readability is a feature that we shall be stressing throughout the text.

Exercises

1 Extend the date conversion example above to add the appropriate suffix to the day. For example, given input:

```
1, 6
```

the program should display '1st June'.

2 The following program fragment illustrates how the computer can select a random question and ask it:

```
10   question = RND(3)
20   PRINT "What was the date of the Battle of ";
30   ON question GOTO 31, 32, 33
31     PRINT "Hastings";:correctanswer=1066 : GOTO 40
32     PRINT "Bannockburn";:correctanswer=1314 : GOTO 40
33     PRINT "Gettysburg";:correctanswer=1863
40   .
     .
```

The value of the variable 'correctanswer' can then be used to check an answer typed at the keyboard. Use this idea to write a program that asks a random question about some topic such as Capital Cities, Authors, Painters, Composers, Dates of Events, etc.

Chapter 4 **Loops**

Loops are one of the most commonly used structures in computer programs. A loop is the colloquial name given to a structure which makes a program do things over and over again. One of the original mechanical computers was called a calculating engine - perhaps a more apt term than computer - having as it does the connotation of a rotating machine churning out numbers. Most practical programs repeat some operations over and over again, albeit on different data each time. A payroll program, for example, may perform exactly the same operations for many employees. A program searching for the occurrence of certain words or phrases in a novel performs the same comparisons over and over again until it reaches the end of the novel. So it is natural that we should have loop facilities available for use in a program.

4.1 Deterministic loops (FOR statements)

Suppose we want to write a program which adds three numbers together. We could write:

```
10   INPUT  n1, n2, n3
20   sum = n1 + n2 + n3
30   PRINT "Sum is "; sum
```

However, if we wanted a program to add 100 numbers together this technique would be somewhat clumsy! If we restructure our summing operation for three numbers like this:

```
 5   sum = 0

10   INPUT n
20   sum = sum + n

30   INPUT n
40   sum = sum + n

50   INPUT n
60   sum = sum + n

70   PRINT "Sum is "; sum
```

then you can see that all we are now doing is repeating a pair of BASIC statements:

```
INPUT n
sum = sum + n
```

three times. Incidentally, because we are accumulating a sum by saying 'sum' becomes equal to what it was before plus 'n', we must ensure that we start off with zero in 'sum'. Most computers do not set variables to zero before they are used - the programmer must do this if necessary - hence line 5.

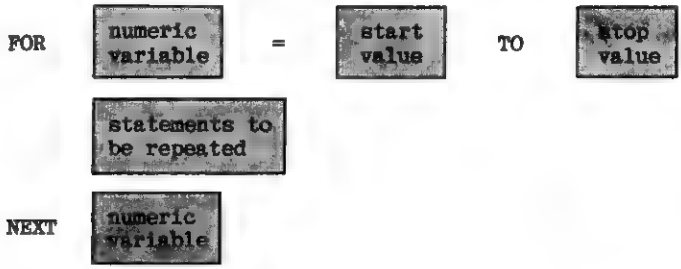
Now we can make the computer obey this pair of statements three times by writing:

```
10  FOR count = 1 TO 3

20      INPUT n
30      sum = sum + n

40  NEXT count
```

or 100 times by writing:

```
10  FOR count = 1 TO 100

20      INPUT n
30      sum = sum + n

40  NEXT count
```

This construction is called a FOR loop and by enclosing a group of statements or a single statement between FOR and NEXT we can make the computer obey a piece of BASIC as many times as we wish. The general form of a simple FOR-NEXT construction is:



The next program takes as input a list of 30 temperature readings and displays the average of these readings.

```
10   sum = 0

20   FOR day = 1 TO 30
30      INPUT temp
40      sum = sum + temp
50   NEXT day

60   average = sum/30
70   PRINT "Average temperature is "; average
```

There are 3 points to note

(1) The FOR statement tells the computer to obey the BASIC statements between FOR and NEXT a number of times specified by the start and stop value.

(2) The numeric variable used after FOR and NEXT is used by the computer to keep track of the number of times it has executed the loop. Each time it goes round the loop the contents of this variable are increased by one. This variable is usually called the 'control variable' because it is used to control the execution of the loop.

(3) The word NEXT is used at the end of the loop to indicate its scope, or tell the computer how many statements are to be included in the loop.

The next program draws 100 random lines in random colours.

```
10   MODE 2
20   FOR line = 1 TO 100
30      GCOL 0, RND(6)
40      DRAW RND(1023), RND(1279)
50   NEXT line
60   keypress = GET
70   MODE 6
```

4.2 Use of the control variable

First look at the following program. The input to the program is the value of a debt, a monthly repayment and an interest rate. The program is to output a list showing the outstanding debt after each monthly repayment has been made.

```
10   @% = &2020A
20   INPUT debt, payment, rate
30   FOR month = 1 TO 12
40      debt = debt + debt * rate/100 - payment
50      PRINT "Debt after next payment is "; debt
60   NEXT month
70   @% = &90A
```

The rather strange 'formatting' statement at line 10 is used without detailed explanation. It tells the computer to print numbers with exactly two digits after a decimal point - very useful when handling money. The statement at line 70 switches the PRINT format back to normal. The use of commas in PRINT statements and the use of formatting is described in Appendix 6. You may, however, prefer to ignore the details and simply use the above as a 'recipe' when it is needed.

Given input of 95, 5, 2 this program will produce output:

```
Debt after next payment is 91.90
Debt after next payment is 88.74
Debt after next payment is 85.51
Debt after next payment is 82.22
Debt after next payment is 78.87
Debt after next payment is 75.44
Debt after next payment is 71.95
Debt after next payment is 68.39
Debt after next payment is 64.76
Debt after next payment is 61.06
Debt after next payment is 57.28
Debt after next payment is 53.42
```

As we have already remarked, the control variable is used by the computer to count how many times the statements following the FOR statement have been obeyed. However, there is no reason why the programmer should not also make use of the value of this variable.

The next program is similar to the previous one except that it now uses the value of the control variable inside the loop. The month number is now printed alongside each balance.

```
10   INPUT debt, payment, rate
20   PRINT "      Month       Outstanding debt"
30   FOR month = 1 TO 12
40      debt = debt + debt * rate/100 - payment
50      PRINT month;
60      @% = &02020A
70      PRINT "      ", debt
80      @% = &90A
90   NEXT month
```

Given input of 1256.75, 56.50, 1.25 this program will generate:

```
Month       Outstanding debt
   1              1215.96
   2              1174.66
   3              1132.84
   4              1090.50
   5              1047.63
   6              1004.23
   7               960.28
   8               915.78
   9               870.73
  10               825.12
  11               778.93
  12               732.17
```

We have had to move the two print-formatting statements inside the loop so that the program keeps switching back to normal format for printing the month number.

The next program draws a regular polygon. The 'radius', the number of sides and the centre are supplied as input. If the number of sides is made very large, the program will draw a circle. If you are not familiar with trigonometry you will have to take the details on trust.

```
 10   INPUT "Radius", r
 20   INPUT "No. of sides", n
 30   INPUT "Centre", cx, cy
 40   theta = 2*PI/n
 50   MODE 1
 60   MOVE cx+r, cy
 70   FOR side = 1 TO n
 80      x = cx + r*COS(side*theta)
 90      y = cy + r*SIN(side*theta)
100      DRAW x,y
110   NEXT side
```

Perhaps we should mention that the trigonometric functions SIN and COS are rather slow, and that there are considerably more efficient techniques available for drawing circles.

Now although it is common practice to use the value of the control variable in such contexts as above, you should never in any circumstances assign to, or attempt to alter the value of the control variable inside the loop. The control variable is the record the machine keeps of how many times it has executed the loop and any interference with this record can have disastrous consequences.

The practice of changing the control variable to force termination of a loop tends to obscure the precise nature of the loop. The same effect can be obtained by using a much

more appropriate construction, a REPEAT loop (see below).

4.3 Non-unit steps in loops

The control variable in a FOR statement can be increased or decreased in non-unit steps by using the word STEP. For example:

```
FOR i = 0 TO 10 STEP 0.2
```

would cause the body of the loop to be executed 51 times with the control variable taking values:

```
0, 0.2, 0.4, 0.6 ... 9.8, 10
```

The use of this facility is illustrated in the next fragment that prints all the multiples of 3 between 3 and 81.

```
10   FOR i = 3 TO 81 STEP 3
20      PRINT i
30   NEXT i
```

In the next program the STEP increment is input from the keyboard. This program produces a conversion table where each row in the table gives the equivalent in gallons of a quantity in litres. The initial imperial quantity and the final imperial quantity together with the increment in gallons between rows in the table are input from the keyboard.

```
10   INPUT startq, stopq, inc
20   FOR gallons = startq TO stopq STEP inc
30      litres = gallons * 4.546
40      PRINT gallons, litres
50   NEXT gallons
```

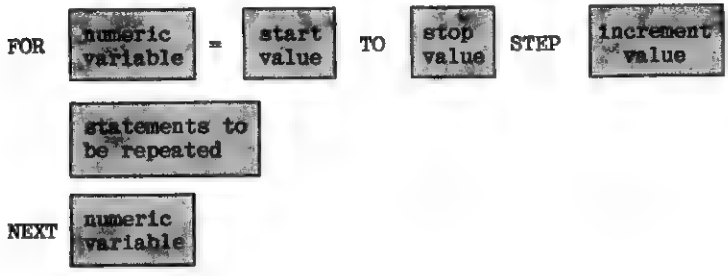
The next program plays a chromatic scale, ie it plays all the semitones in an octave.

```
10   FOR pitch = 1 TO 49 STEP 4
20      SOUND 1, -15, pitch, 20
30   NEXT pitch
```

The next program draws an outline of a bar-chart or histogram. The values giving the heights of each bar are given in a DATA statement.

```
 10   DATA 200,400,500,700,900,875,850,800,600,150
 20   MODE 1
 30   y = 100
 40   MOVE 0,y : DRAW 1279,y : MOVE 100,y
 50   FOR x = 100 TO 1000 STEP 100
 60      READ height
 70      DRAW x, y + height
 80      DRAW x + 100, y + height
 90      DRAW x + 100, y
100   NEXT x
```

The general form of a FOR...NEXT construction can thus be extended to:



Exercises

1 Write a program that inputs and adds together 15 numbers and then prints their average. Now modify your program so that it inputs an integer n followed by n numbers. The program should display the average of the n numbers.

2 Change the program at the end of Section 4.1 to use a wider range of colours. (You can use RND(15).)

3 Write a program to print a '4 times table' in the form:

```
1 x 4 = 4
2 x 4 = 8
3 x 4 = 12
   etc.
```

Now modify your program so that it reads an integer, n say, and prints out an "n times table".

4 The statement

```
SOUND 1, -15, f, 5
```

makes a sound whose frequency depends on the value of f

which can be anything from 0 to 255. Write a program that plays through the entire available frequency range.

5 Write a program that plays through the available frequency range in 'perfect fifths'. The interval of a perfect fifth contains 7 semitones (or 28 quarter semitones).

6 Try the effect of the statement

```
r = r + 5
```

inside the loop of the polygon drawing program. Now change the program so that it draws a spiral that fills the screen.

4.4 REPEAT-UNTIL loops

Now the loops we have just looked at are called deterministic loops - the number of times the loop is to be executed is predetermined or known. The program knows before the loop is obeyed how many daily temperatures are to be averaged or how many monthly balances have to be calculated.

The next type of loop we are going to look at is a REPEAT-UNTIL loop. This is used when it is not possible to calculate, before entering the loop, how many times the loop is to be executed. We write the program using a REPEAT-UNTIL structure which means that a statement or group of statements are REPEATed UNTIL a condition is satisfied. For example, suppose we wish to use the keyboard as a simple adding machine: each number we type is to be added to an accumulating sum. Thus, the statements that are to be repeated are as before:

```
INPUT n
sum = sum + n
```

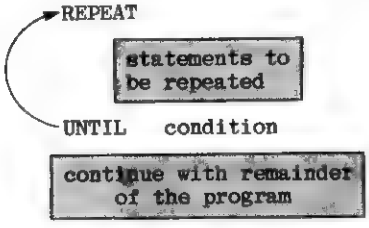
However, this time let's assume that we do not know in advance how many numbers are to be included in the sum. This would be the case, for example, with a supermarket checkout program where the number of items is, of course, variable. We want the program to keep summing the numbers we type until we give it a signal to stop - say by typing zero. This can be summarised by:

```
REPEAT

   INPUT n
   sum = sum + n

UNTIL 0 has been typed
```

This program sums a list of numbers terminated by a zero.

```
 5   sum = 0
10   REPEAT
20     INPUT n
30     sum = sum + n
40   UNTIL n = 0
50   PRINT "Sum is "; sum
```

The general form of such a structure is:



The next program is a trivial example of a computer assisted learning (CAL) program. It repeats an arithmetic problem until the user gives the correct answer. An arithmetic problem such as '16 + 25 = ?' is posed. The user is to input the answer and the program is to check the answer, repeating the question until the answer is correct.

```
10   a = RND(20) : b = RND(20)
20   tries = 0
30   REPEAT
40     PRINT a; "+"; b; "=";
50     INPUT answer
60     tries = tries + 1
70   UNTIL answer = a + b
80   PRINT "Got it! after "; tries; " tries"
```

Here is another variation on this theme. This program keeps setting different random multiplication questions and reading the answers typed at the keyboard. The program stops when a wrong answer is typed and prints a message indicating how many correct answers were typed.

```
 10   questions = 0
 20   REPEAT
 30      questions = questions + 1
 40      a = RND(11) + 1  :  b = RND(11) + 1
 50      PRINT a; "x"; b; "=";
 60      INPUT answer
 70   UNTIL answer <> a*b
 80   SOUND 1, -15, 0, 50
 90   PRINT "You got "; questions-1; " right"
100   IF questions > 20 THEN  PRINT "Well done!"
```

Remember that the expression 'RND(11) + 1' gives a random number in the range 2 to 12.

4.5 Data terminators

The first program of the last section illustrated a widely used programming structure. A list of input values was processed and the program was such that it could cope with lists of any length. This was accomplished by adding a special code to the bottom of the list to terminate it. We call such a code a data terminator and now examine its use in greater detail. Look at the next program. It adds a sequence of positive numbers together. The sequence is terminated by a single negative number.

```
10   sum = 0
20   INPUT next
30   REPEAT
40     sum = sum + next
50     INPUT next
60   UNTIL next < 0
70   PRINT "Sum is "; sum
```

This program illustrates a common feature of conditional loops: the next value to be processed is obtained at the end of the loop so that this value is tested before it is processed. This necessitates obtaining the first value before entering the loop. In the last section, we cheated by making the data terminator a zero so that it had no effect on the sum.

It is interesting to consider a number of alternative constructions for the loop in the above program, all of which are occasionally produced by beginners and all of which are **wrong**.

```
sum = 0
REPEAT
   INPUT next
   sum = sum + next
UNTIL next < 0
```

This would add the data terminator, which is a negative number, to the total.

```
sum = 0
INPUT next
REPEAT
   INPUT next
   sum = sum + next
UNTIL next < 0
```

This would not add the first number onto the total and would again add the data terminator onto the total.

```
sum = 0
REPEAT
   INPUT next
   sum = sum + next
   INPUT next
UNTIL next > 0
```

This version adds together the first, third, fifth, etc. numbers in the data and tests the second, fourth, sixth, etc.

If the numbers in the input are being handled in groups of two or more, care has to be taken in handling data terminators. The neatest solution is to insert a group of data terminators which contains the same number of values as the groups into which the rest of the data is organized, as in the next program.

Voting takes place for two political parties in a number of constituencies. The two vote-totals for each constituency are typed in pairs as input to a program and two negative numbers are typed in the input when all pairs of totals have been typed. This program adds up the overall totals for the two parties and reports the overall result.

```
 10   party1overall = 0
 20   party2overall = 0
 30   INPUT party1next, party2next

 40   REPEAT
 50     party1overall = party1overall + party1next
 60     party2overall = party2overall + party2next
 70     INPUT party1next, party2next
 80   UNTIL party1next < 0

 90   PRINT "Party1: "; party1overall
100   PRINT "Party2: "; party2overall
```

If presented with input:

```
 3, 7
 5, 9
 4, 2
-1,-1
```

this program will output

```
Party1: 12
Party2: 18
```

The logical structure of this program is the same as that of the previous one except that the input values are processed in pairs. Two data terminators are needed in order that they can be read by the same statement that reads the other pairs of values. (The first data terminator must be negative and the test for termination of the loop needs to examine only the first value of each pair.) If we wish to type only one data terminator at the end of the input data, a slightly more difficult structure is required for the loop:

```
10   INPUT party1next
20   REPEAT
30     INPUT party2next
40     party1overall = party1overall + party1next
50     party2overall = party2overall + party2next
60     INPUT party1next
70   UNTIL party1next < 0
80   PRINT party1overall, party2overall
```

This version reads only one number at the end of the loop and tests it. Only if this value is not the terminator can a second value be safely read. In addition to being slightly more difficult, this version requires the input values to be typed on separate lines. (Each INPUT statement expects its input values to start on a new line.)

The following program also handles values two at a time. It will play a tune specified in a DATA statement. The values in the DATA statement come in pairs giving the frequency and duration for each note.

```
1   DATA  0,10, 0,10, 28,10, 28,10, 36,10, 36,10, 28,20
2   DATA 20,10, 20,10, 16,10, 16,10, 8,10, 8,10, 0,20
3   DATA  0, 0

10  READ freq, length
20  REPEAT
30     SOUND 1, -15, freq, length
40     READ freq, length
50  UNTIL length=0
```

One problem that will be immediately apparent if you run this program is that consecutive notes of the same pitch will be 'slurred' - there is no gap between notes. A note of zero duration could be inserted between identical notes (see Chapter 1, Section 1.8).

Finally, we present a program in which two REPEAT-UNTIL loops are used one after the other. This program adds up the overall totals for the two parties in an election, but the constituency subtotals for one party are all typed first in the input and are terminated by a negative number. The subtotals for the second party are then typed and are also terminated by a negative number.

```
10   party1overall = 0
20   INPUT party1next
30   REPEAT
40     party1overall = party1overall + party1next
50     INPUT party1next
60   UNTIL party1next < 0

70   party2overall = 0
80   INPUT party2next
90   REPEAT
100    party2overall = party2overall + party2next
110    INPUT party2next
120  UNTIL party2next < 0

130  PRINT "party1: "; party1overall
140  PRINT "party2: "; party2overall
```

The second loop is not encountered until the first loop has been obeyed the appropriate number of times. The first REPEAT-UNTIL loop is obeyed until the first negative number is read and only then can the program carry on to obey the

next loop. The input for the program might consist of the numbers

```
3  5  4  -1
7  9  2  -1
```

where each number has to be typed on a separate line. The input could even consist of the numbers:

```
2  3  7  9  4  -1
1  7  6  -1
```

if candidates for party 1 are standing for election in more constituencies than are candidates for party 2.

4.6 Use of logical variables in loops

A logical variable often provides a neat way for a programmer to express the terminating condition for a loop, and to test subsequently why the loop was terminated. Consider the following program which reads input consisting of 365 pairs of values, one pair for each day of the year. The first number in each pair is the average temperature for the day and the second is the number of hours of sunshine for the day. The program counts how many days elapsed before the first day on which both the average temperature exceeded 15 degrees and the number of hours of sunshine exceeded 10. The program caters for the possibility that there is no such day.

```
10   day = 0
20   warmdayfound = FALSE

30   REPEAT
40     day = day + 1
50     INPUT nextemp, nextsun
60     warmdayfound = nextemp > 15 AND nextsun > 10
70   UNTIL warmdayfound OR (day = 365)

80   IF warmdayfound THEN
       PRINT "There were ";
             day - 1; " days before the 1st. good day."
     ELSE   PRINT "A bad year!"
```

More realistically, the data for this program would be held on a file and input from there (see Appendix 2).

Exercises

1 An organisation has approximately $10000 available to be allocated in small amounts to approved charities. The

amounts approved for each charity are to be typed as input for a program in the order in which the requests are received. Write a program that will read in these amounts and report as soon as over $10000 has been allocated.

2 In the first CAL program of Section 4.4, the output produced by the program is occasionally a little ungrammatical. Correct this.

3 Write a program that accepts a person's initial bank balance followed by a sequence of positive and negative real numbers representing transactions. A positive number represents a credit entry in the account and a negative number represents a debit entry. The input is terminated by a zero entry. The program should print the new balance.

4 Write a program that switches to MODE 1 and then draws a picture under the control of a user seated at the keyboard. The user will repeatedly type a pair of x-y coordinates telling the program to which point it should next draw a line. The program should terminate and switch back to MODE 6 when two negative values are typed. The function TAB can be used to keep the cursor out of the way of the picture being drawn. For example,

```
PRINT TAB(0,0); "                    " ; TAB(0,0);
```

moves the character cursor to the top left-hand corner of the screen and wipes out any numbers already displayed at the start of the first line of the screen. This could be done by the program before input of each pair of numbers.

4.7 Timing delays

A timing element is used in many contexts in computer programming. Measuring time and acting upon particular timing signals is a feature of real-time programming. In using your computer there are many contexts in which you might make timing measurements. For example: as an element in games; as a delay in animation (see Chapter 11); or in simply slowing the rate at which a continuous sequence or list of information is displayed on the screen. Look again at the first program in Section 4.2. Suppose we wanted a 1 second delay between the appearance of each new line on the screen. We could proceed as follows:

```
20    FOR month = 1 TO 12
30       debt = debt + debt*rate/100 - payment
40       PRINT "debt after next payment is ", debt
50       ****  delay proceedings for 1 sec. ****
60    NEXT month
```

Now we can set up a delay in two ways. Firstly we can use an empty FOR statement:

```
50    FOR i = 1 TO 1450 : NEXT i
```

We know that the Electron takes approximately 1 second to execute this empty loop. Although the loop is not doing anything the computer has no knowledge of this and still has to set up its loop housekeeping operations. (Incidentally we have now introduced a loop within a loop. This structure is examined in more detail in Chapter 5.)

More appropriately, we can use the function TIME. You can imagine TIME as a numeric variable that can be initialised and is then increased by 1 every 1/100th of a second. Thus a 1 second delay using this facility would be obtained by

```
50    TIME = 0 :  REPEAT : UNTIL TIME > 100
```

Timing delays can also be obtained by using the INKEY function which is described in later chapters.

Exercises

1 Extend the polygon drawing program of Section 4.2 so that it waits for 30 seconds after completing its pattern and then switches back to MODE 6.

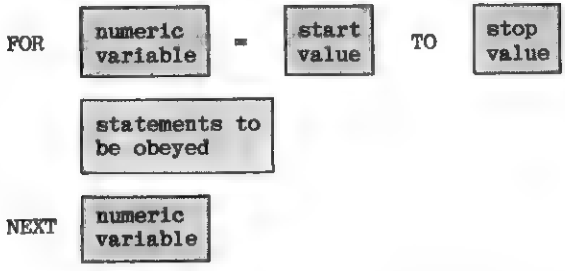
2 Extend the second CAL program of Section 4.4 so that it stops either when a wrong answer is typed or when a maximum time limit has been exceeded.

Chapter 5 Statements within statements

IF statements and loops are examples of 'control structures' that control the order in which parts of a program are obeyed. Sometimes one control structure needs to be included inside another. For example it is possible to have a conditional statement inside a loop, a loop within a conditional statement and loops within loops. In this chapter we demonstrate how to write programs involving some of the most commonly occurring nested control structures.

5.1 IF statements within loops

We have seen in Chapter 3 that a FOR statement can take the form



A statement to be obeyed repeatedly can in fact be any BASIC statement. We now illustrate the case where an IF statement is obeyed repeatedly by writing a program to print all the integers between 2 and 9 which divide exactly into a given integer. We can describe in outline what the program must do:

```
10   INPUT giveninteger
20   FOR i = 2 TO 9
         statement to test whether i divides
         exactly into the given integer
40   NEXT i
```

In order to test whether an integer 'i' divides exactly into 'giveninteger' we can use

```
30   IF giveninteger MOD i = 0 THEN
        PRINT ;i; " divides into the given integer"
```

and this is the statement that must follow the above FOR statement. So putting them both together we get the following program.

```
10   INPUT giveninteger
20   FOR i = 2 TO 9

30      IF giveninteger MOD i = 0 THEN
          PRINT ;i; " divides into the given integer"

40   NEXT i
```

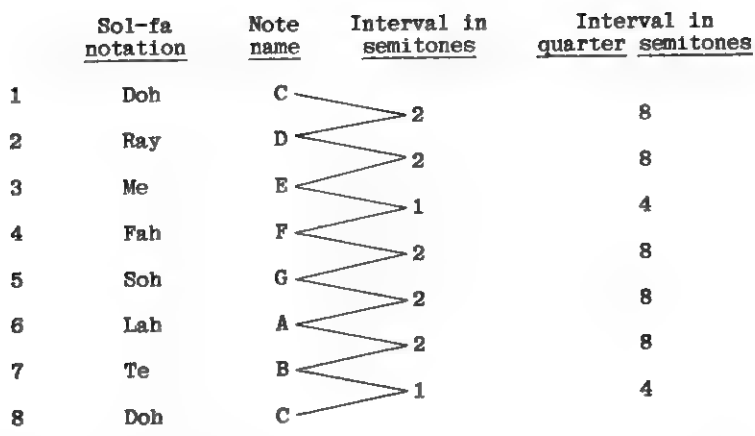
The FOR statement in the above program will behave as if a sequence of eight separate IF statements were obeyed:

```
IF giveninteger MOD 2 = 0 THEN
  PRINT ;2; " divides into the given integer"

IF giveninteger MOD 3 = 0 THEN
  PRINT ;3; " divides into the given integer"

IF giveninteger MOD 4 = 0 THEN
  PRINT ;4; " divides into the given integer"

      .
      .
      .
IF giveninteger MOD 9 = 0 THEN
  PRINT ;9; " divides into the given integer"
```

Thus, given input of 18, the program will print

```
2 divides into the given integer
3 divides into the given integer
6 divides into the given integer
9 divides into the given integer
```

The next program demonstrates one possible way of making the computer play a major scale. The following table shows the intervals between the notes of the scale of C major.



Middle C corresponds to frequency code number 53. Thus the statement

```
SOUND 1, -15, 53, 20
```

plays Middle C for about one second. To play the scale of C major, we could use

```
10   pitch = 53
20   FOR note = 1 TO 8
30      SOUND 1, -15, pitch, 20
40      IF note=3 OR note=7 THEN  pitch = pitch + 4
                            ELSE  pitch = pitch + 8
50   NEXT note
```

The next program includes an IF statement within a REPEAT-UNTIL loop. It is an elaboration of one of the computer assisted learning programs of the last chapter. The program is now made more realistic by including within the REPEAT loop an IF statement that allows an appropriate message to be printed.

This program also illustrates another common problem in loop programming. Frequently, when a loop is terminated, the reason for the termination must be known so that it can be used, for example to print an appropriate message. Using logical variables - or state variables as they are technically known - gives a neat way of doing this.

```
10   tries = 0
20   a = RND(100) : b = RND(100)
30   REPEAT
40      PRINT a; " + "; b; " = ";
50      INPUT answer
60      correct = (answer = a + b)
70      IF NOT correct THEN PRINT "No!"
80      tries = tries + 1
90   UNTIL correct OR tries = 3

100  IF correct THEN
        PRINT "Got it after "; tries; " tries."
     ELSE
        PRINT "Sorry you have had 3 tries." :
        PRINT "The correct answer is "; a + b
```

The next program illustrates the use of several IF statements inside a REPEAT loop. It also uses the function GET$ which 'gets' the next character typed at the keyboard without the character being displayed on the screen.

This program acts as a simple graphics 'sketchpad' under the control of a user seated at the keyboard. (Compare this program with the exercise set at the end of Section 4.6.) The user inputs a start position (x-y coordinates) and then draws a picture by repeatedly typing a character "N", "S", "E" or "W". Each character typed by the user causes the line drawn by the program to be extended a short distance in the direction indicated (North, South, East or West). The program terminates when the character "Q" for Quit is typed.

```
10   INPUT "Start position", x, y
20   MODE 1
30   MOVE x, y

40   REPEAT
50      c$ = GET$
60      IF c$ = "N" THEN y = y + 4
70      IF c$ = "S" THEN y = y - 4
80      IF c$ = "E" THEN x = x + 4
90      IF c$ = "W" THEN x = x - 4
100     DRAW x,y
110  UNTIL c$ = "Q"

120  MODE 6
```

Exercises

1 Given input consisting of 30 numbers, some of which are positive and some negative, write a program that finds

the average of the positive numbers and the average of the negative numbers.

2 The Scottish bagpipe scale starts on the A above Middle C (pitch code number 89). The intervals between successive notes (in quarter semitones) are approximately 8, 6, 6, 8, 6, 6, 8. Incidentally, these notes are not all available on a piano. Write a program that plays a Scottish bagpipe scale.

3 Another way of playing a scale would be to insert the 8 required pitch values in a DATA statement. The scale could then be played with a simple FOR loop. Do this.

4 Modify the CAL program of the last section so that it times the user and prints an appropriate message telling him how long it took him to find the correct answer.

5 Extend the sketchpad program so that the line can be switched on or off by means of two other keys. One way of doing this would be to use a logical variable in which the program keeps a record of whether the line is on or off. Another way would be to switch colours using GCOL. Switching the line off would correspond to making the current plotting colour the same as the background colour (GCOL 0,0).

When the line is off, you will find that you have no idea where on the screen you are. You will be able to deal with this problem when you have read Chapter 9.

5.2 Loops within loops

One loop inside another loop is a nested structure frequently encountered in programs. This is because so much data analysed by computer programs is organised in the form of tables.

Consider the problem of processing the 5 examination marks obtained by each of 25 candidates. The structure required is a loop of the form

```
FOR candidate = 1 TO 25
    process the marks obtained
    by the candidate
NEXT candidate
```

Processing one candidate's marks might involve reading the 5 marks obtained by the candidate, computing his average and testing for a pass or fail:

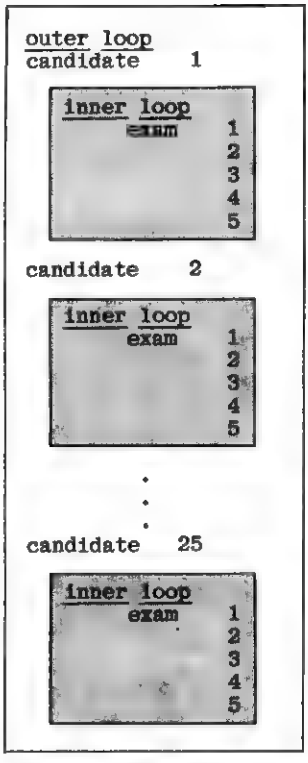
```
10   total = 0
20   FOR exam = 1 TO 5
30     INPUT mark
40     total = total + mark
50   NEXT exam

60   average = total/5
70   IF average >= 50 THEN
       PRINT "Passed! Average is "; average
     ELSE
       PRINT "Failed! Average is "; average
```

and a segment of program like this must be obeyed 25 times. This is achieved simply by inserting the the above fragment in its entirety into the 'candidate', loop making a loop within a loop structure:

```
 5   FOR candidate = 1 TO 25

10     total = 0
20     FOR exam = 1 TO 5
30       INPUT mark
40       total = total + mark
50     NEXT exam

60     average = total/5
70     IF average >= 50 THEN
         PRINT "Passed! Average is "; average
       ELSE
         PRINT "Failed! Average is "; average

80   NEXT candidate
```

Incidentally, in practice, input would of course be taken from a file (see Appendix 2). In this particular example can you see what the difference would be, as far as the screen display is concerned, between file input and keyboard input?

In the above program the outer loop is executed 25 times. Once the computer enters the innermost loop, it stays there until this loop has been executed 5 times. The innermost pair of instructions at lines 30 and 40 are executed a total of 25x5 times and 125 marks are supplied as input in the form of 25 groups of 5 marks. If we imagine a counter associated with each loop, then the 'exam' counter would be turning 5 times as fast as the 'candidate' counter, resetting to 1 for each new candidate.



To improve your understanding of the idea of a nested loop, you should examine the difference in behaviour between the following two fragments of program.

```
10   FOR i = 1 TO 3
20     FOR j = 1 TO 3
30       PRINT i,j
40     NEXT j
50   NEXT i
```

prints

```
1          1
1          2
1          3
2          1
2          2
2          3
3          1
3          2
3          3
```

```
10   FOR i = 1 TO 3
20     PRINT i
30   NEXT i
40   FOR j = 1 TO 3
50     PRINT j
60   NEXT j
```

prints

```
1
2
3
1
2
3
```

The first fragment is of course a nested structure, whereas the second is just two consecutive loops.

As a further illustration, let us construct a program that will display a triangle of stars (of a given size) on a background of dots. For example a triangle of 4 lines would be:

```
.........
....*....
...***...
..*****..
.*******.
.........
```

In outline, the program required will behave as follows:

```
10   INPUT noofrows
20   *** calculate width of picture ***

30   FOR ch = 1 TO widthofpic : PRINT "."; : NEXT ch
40   PRINT

50   FOR rowno = 1 TO noofrows

       ***  print the next row of the triangle with  ***
       ***   appropriate no. of dots on either side  ***

60   NEXT rowno

70   FOR ch = 1 TO widthofpic : PRINT "."; : NEXT ch
```

The width of the picture is given by '2*noofrows + 1'. Printing a row of the triangle can be described in more detail as:

```
Calculate number of stars in this row
Calculate number of background dots at each end of  row
FOR ch = 1 TO noofdots : PRINT "."; : NEXT ch
FOR ch = 1 TO noofstars: PRINT "*"; : NEXT ch
FOR ch = 1 TO noofdots : PRINT "."; : NEXT ch
```

The number of stars to be printed on a row is '2*rowno - 1' and the number of background dots required is 'noofrows + 1 - rowno'. These loops must be nested inside the second loop in the outline above because our triangle is made up of a number of such lines. Filling in these details we get the following program:

```
10   INPUT noofrows
20   widthofpic = 2*noofrows + 1

30   FOR ch = 1 TO widthofpic : PRINT "."; : NEXT ch
40   PRINT

50   FOR rowno = 1 TO noofrows
51      noofstars = 2*rowno - 1
52      noofdots  = noofrows + 1 - rowno
53      FOR ch = 1 TO noofdots : PRINT "."; : NEXT ch
54      FOR ch = 1 TO noofstars: PRINT "*"; : NEXT ch
55      FOR ch = 1 TO noofdots : PRINT "."; : NEXT ch
56      PRINT       :REM to start a new line.
60   NEXT rowno

70   FOR ch = 1 TO widthofpic : PRINT "."; : NEXT ch
```

The final example in this section involves an IF statement inside a REPEAT-UNTIL loop inside a FOR loop.

Part of a daily sales analysis program involves printing a list of the number of items costing more than $10 that were sold in each of 63 departments:

```
FOR dept = 1 TO 63
   analyse the sales for one department
NEXT dept
```

The input for each department consists of a list containing the price of each item sold in the department on the day in question, and each list is terminated by -1. One department's sales can therefore be analysed by:

```
20    largesales = 0
30    INPUT nextitemprice

40    REPEAT
          test 'nextitemprice' to see
          if it is  a large  sale
60      INPUT nextitemprice
70    UNTIL nextitemprice < 0
```

Filling in the rest of the details we obtain:

```
10   FOR dept = 1 TO 63
20     largesales = 0
30     INPUT nextitemprice

40     REPEAT
50       IF nextitemprice >= 10 THEN
           largesales = largesales + 1
60       INPUT nextitemprice
70     UNTIL nextitemprice < 0

80     PRINT "Dept no. "; dept; " has made ";
           largesales; " largesales"
90   NEXT dept
```

Exercises

1 Write a program that accepts, as input, two numbers representing the width and height of a rectangle. The program is then to print such a rectangle made up of asterisks, for example:

```
*********
*********
*********
*********
```

2 Write a program to accept a single integer and print a multiplication table for all the positive integers up to the one specified as input.

5.3 Nested IF statements

Consider the following sequence of three IF statements:

```
10   IF age < 21  THEN PRINT "Refuse policy"
20   IF age >=35  THEN PRINT "Issue policy with discount"
30   IF age >=21 AND age < 35 THEN
                        PRINT "Issue policy at full price"
```

Here three consecutive IF statements are used to select one of three possible courses of action. The three conditions used are such that one and only one of them must be TRUE. However, even if the condition in the first IF statement is TRUE, the computer will still waste time testing the conditions in the remaining two IF statements. If the conditions in the first two IF statements are FALSE, the condition in the third must be TRUE and the computer will again waste time testing it. These inefficiencies can be eliminated by using a more appropriate IF statement structure for making the tests involved. Let us start by noting that IF age < 21 then the first write statement should be obeyed and no further tests made. This can be achieved by using an IF-THEN-ELSE structure which can be outlined as:

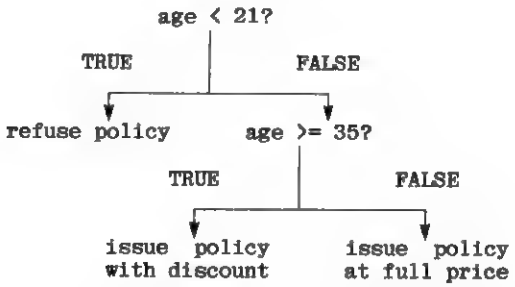
```
10   IF age < 21 THEN PRINT "refuse policy"
     ELSE
          statement to be obeyed
          only if age >= 21
```

Any statement inserted after the ELSE will be obeyed only if age >= 21. In this example we can obtain the effect we require by making the statement after the ELSE a further IF statement which distinguishes the cases age >= 35 and age < 35:

```
10   IF age < 21 THEN PRINT "Refuse policy"
     ELSE
       IF age >= 35 THEN PRINT "Issue with discount"
                    ELSE PRINT "Issue at full price"
```

Note that this is a single statement as far as Electron BASIC is concerned and has only one line number. This version of the program will not test the second condition if the first is satisfied and will automatically obey the third PRINT statement if the first two conditions are FALSE. We

can illustrate the behaviour of this nested IF statement as follows:



We can imagine the computer following one path from the top of this diagram and carrying out the action at the end of that path.

Unfortunately, the extent to which we can nest IF statements in Electron BASIC is limited in several ways. For example, unexpected effects can be obtained if we use an IF-THEN-ELSE after the THEN of another IF statement. (You will find that the computer can not decide to which IF the ELSE belongs.) We are also limited by the restriction that our complete nested IF statement must fit into 240 characters (6 lines in MODE 6). We suggest that the use of nested IF statements is limited to the use of IF after ELSE as illustrated above.

The standard way of implementing more complex IF structures in other BASIC dialects is to use the GOTO statement. However, the techniques introduced in Chapter 7 will enable us to program complex nested control structures without resorting to the use of GOTO.

Exercises

1 Write a program that inputs two person's names, each name being followed by their age. The program should output a message stating whether they are the same age and, if not, it should state who is older.

5.4 Stepwise refinement

In writing some of the programs in this chapter, we have informally introduced the technique that is sometimes termed 'stepwise refinement' or 'top-down program design'. Instead of attempting to write down a complete BASIC program in one step, we first decide what the outermost control structure in the program should be. For example, in writing our sales analysis program, we could see immediately that there were

63 separate sales analyses to be made. Giving a brief English description to the process of analysing one department's sales enabled us to write down an outline of this loop:

```
FOR dept = 1 TO 63
    analyse the sales for one department
NEXT dept
```

Having got this clear in our minds, we then concentrated on the rather easier sub-problem of analysing one department's sales and the program for doing this was eventually inserted in the above structure. This sub-problem was of course tackled by a further application of stepwise refinement.

Such an approach enables the construction of a complex nested control structure to be broken down into a number of simpler programming tasks that are more or less independent of each other.

As another example, we may require a computer assisted learning program that repeatedly sets a new problem until the user of the program indicates that he wishes to stop. The program should always wait until a correct answer to the last problem has been input before going on to the next one. The section of program for setting a problem and processing the user's attempts at an answer may be quite complicated, but before considering the details of this process we must plan the overall structure of the program:

```
REPEAT
    Set a problem and process the answer
        (repeating the problem if necessary)
    INPUT "More? Y/N:" reply$
UNTIL reply$ = "N"
```

We are now free to concentrate on the details of setting a single problem and processing the answer. A version of this sub-problem has already been dealt with in Section 5.1 and the present program can be completed by inserting the previous solution at the appropriate place in the above outline:

```
  5   REPEAT
 10      tries = 0
 20      a = RND(100) : b = RND(100)
 30      REPEAT
 40         PRINT a; " + "; b; " = ";
 50         INPUT answer
 60         correct = (answer = a + b)
 70         IF NOT correct THEN PRINT "Wrong!"
 80         tries = tries + 1
 90      UNTIL correct OR tries=3

100      IF correct THEN
            PRINT "Got it after "; tries; " tries."
         ELSE
            PRINT "Sorry you have had 3 tries." :
            PRINT "The correct answer is "; a + b

110      INPUT "More? Y/N:" reply$
120   UNTIL reply$ = "N"
```

Stepwise refinement is just one aspect of the set of programming techniques known as 'structured programming'. Stepwise refinement is discussed further in Chapter 7 when we introduce techniques for giving names to different sections of a program.

Chapter 6 **Handling lists**

If a program systematically processes a collection of variables, it may not be convenient for the programmer to give each of these variables a different name. For example, it would be rather tedious to write:

```
totalprice = priceofhammer + priceofsaw     +
             priceofaxe    + priceofplane   +
             priceofchisel + priceofvice    +
             priceofscrewdr+ priceofspanner
```

Instead of giving such a group of variables separate names, it is often more convenient to give them a collective name and to refer to the individual variables in the collection by a reference number or 'subscript'.

6.1 One-dimensional arrays

A one-dimensional array is a set of storage locations, or variables, all of the same type, which share the same name but have different subscripts. For example the information:

Name of variable	Contents
priceofhammer	5.77
priceofsaw	3.15
priceofaxe	2.50
priceofplane	16.33
priceofchisel	2.50
priceofvice	13.45
priceofscrewdr	.86
priceofspanner	1.98

could be stored in a one-dimensional array:

Name of variable	Contents
priceof(1)	5.77
priceof(2)	3.15
priceof(3)	2.50
priceof(4)	16.33
priceof(5)	2.50
priceof(6)	13.45
priceof(7)	.86
priceof(8)	1.98

The very first thing we have to do with this type of storage facility is to tell the computer that we are going to use it and how long our list or lists will be. The computer needs to set aside enough space for all the variables in a list.

Suppose we had 1000 item prices to store. Right at the beginning of the program we write

```
DIM   priceof(1000)
```

DIM is short for dimension and this statement informs the computer that we want 1000 variables all referred to by the same name - 'priceof'. In computer parlance such a list is called a one-dimensional array and the individual boxes are called array elements. Now, from within a program, array elements can be treated as ordinary variables. For example we could write:

```
PRINT "The price of item 2 is "; priceof(2)
```

and the computer would print out the contents of the second variable in the list. Similarly we could write:

```
PRINT "The price of item 57 is "; priceof(57)
```

and the computer would print out the value of the 57th variable in the list.

Here is an example that performs a simple calculation using array elements.

```
PRINT "Price difference between items 5 and 12 is ";
PRINT ;ABS (priceof(5) - priceof(12))
```

This simply prints out the difference between the values of the 5th and 12th variables in the list. Actually, the DIM statement reserves storage locations numbered from zero upwards, but in many situations it is convenient, and less confusing, to ignore location zero.

These examples show how we set up a list and how

individual elements can be treated as single variables. We now move on to the more general considerations involved in using such lists.

6.2 Systematic and random access to array elements

One point of having an array facility is that it is easy to carry out the same operation on all the elements in the list. For example, if we wanted to find the total cost of all the items in 'priceof' we would write:

```
110   cost = 0
120   FOR item = 1 TO 1000
130      cost = cost + priceof(item)
140   NEXT item
150   PRINT "Cost of all items is "; cost
```

Here we have used a deterministic loop to systematically process all the elements in the array. The control variable 'item' varies from 1 to 1000 and 'priceof(item)' refers successively to

```
priceof(1)
priceof(2)
priceof(3)
    .
    .
    .
priceof(1000)
```

as the loop progresses. Line 30 is thus a general statement specifying that the contents of an array element are to be accumulated into 'cost'. The particular element accessed is determined by the value of the control variable, which of course is incremented by one each time through the loop. We thus have a facility for referring to consecutive elements in the array. It is important to note that each array element has two quantities associated with it:

(1) its reference number or subscript, and
(2) its contents.

The next program is a simulation of a catalogue system which, in its simplest form, might be a list of prices and implied reference numbers: 1,2,3,...etc. It inputs 1000 prices from a file (see Appendix 2) to be stored in an array. The program then continually loops requesting a reference number in the range 1 to 1000. On receipt of the reference number it is to type out the corresponding price. The loop terminates when a stop code is typed.

```
 10   DIM priceof(1000)
 20   prices = OPENIN ("pricelist")
 30   FOR item = 1 TO 1000
 40     INPUT# prices, priceof(item)
 50   NEXT item
 60   CLOSE# prices

 70   INPUT ref
 80   REPEAT
 90     PRINT "Price of item "; ref; " is "; priceof(ref)
100     INPUT ref
110   UNTIL ref = 0
120   PRINT "You have terminated the program."
```

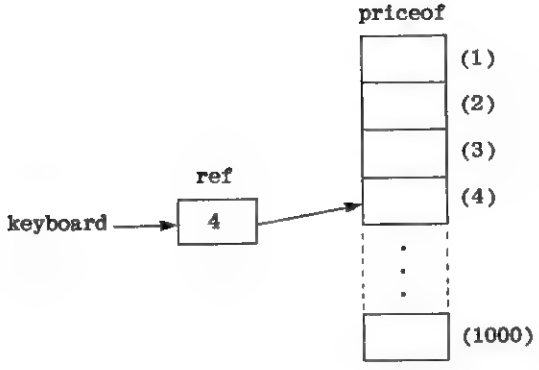
Now in this program there are two loops. The first, lines 30 to 50, is a deterministic loop systematically going through the array. It is equivalent to writing

```
INPUT# priceof(1)
INPUT# priceof(2)
INPUT# priceof(3)
       .
       .
       .
INPUT# priceof(1000)
```

and this loads 1000 prices from the input file into consecutive array elements.

In practice this is a program that may run all day in a warehouse until a stop code (zero) is typed. The first loop is obeyed as soon as the program is started and takes input from a magnetic disk or cassette file. The program would normally be waiting inside the second loop at line 90 for a 'ref' number to be typed.

When a reference number is typed the computer prints out the contents of the corresponding array element. This is called random access because the computer accesses any element out of the 1000 depending on which number is input to the numeric variable 'ref'. This is illustrated in the diagram below. Any number in the range 1 to 1000 is typed into the numeric variable 'ref'. The computer then prints out the contents of 'priceof(ref)'. The contents of 'ref' point to the desired array element. This is an extremely important facility in computer programming and is used extensively in data structures and databases.



6.3 Subscript range

In the above example if you input a number from the keyboard that is less than 0 or greater than 1000 then the program will fail and execution will terminate with an error message. This is because the computer detects that you have tried to access an element that does not exist. You will find that when you start working with arrays this is one of is the commonest errors you will make.

It is always good programming practice to check that subscripts typed from a keyboard are in range. It is true that if you attempt to use an out of range subscript, then this will be trapped by the computer and an execution error will occur. However there are two consequences of this:

(1) The program will terminate unexpectedly.

(2) If you are writing the program for use by a third party, who may not necessarily know a lot about computers, then a subscript error message followed by program termination could be baffling.

To make the program more robust we could write:

```
 70   INPUT ref
 80   REPEAT
 90      IF ref<0 OR ref>1000 THEN  PRINT "Invalid code"
         ELSE  PRINT "Price of item "; ref;
                              " is "; priceof(ref)
100      INPUT ref
110    UNTIL ref = 0
```

The program is not yet completely foolproof: what happens if zero is typed as soon as the program is obeyed? How should

this be dealt with?

Exercises

1 Write a program that inputs a list of numbers and prints them in reverse order.

2 Write a program that reads a price list for 10 items from a file. The program is then to accept a list of 10 quantities required by a customer, for example:

```
 5      means  5 of item  1
 0      means  0 of item  2
12      means 12 of item  3
          :
27      means 27 of item 10
```

The program should calculate the total cost of the customer's order.

3 As Exercise 2 but this time the program is to accept a list of pairs where each pair contains an item number followed by the quantity required. The item numbers appear in any order and the list can contain any number of orders, for example:

```
10, 2     means 10 of item 2
25, 4     means 25 of item 4
 3, 2     means  3 of item 2
            :
65, 9     means 65 of item 9
 0, 0     means the end of the list.
```

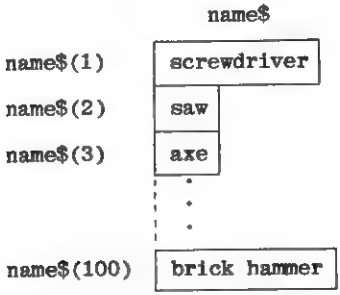
The program should check that each item number typed does in fact exist.

4 Write a program to quote, in weeks and days, the duration between two specified dates. Both dates are in the same year and each date is in the form of two integers: the first is the day and the second is the month. The dates are supplied as input. The numbers of days in each month of the year should be included in a DATA statement. (These DATA values should be read by the program into an array.) Assume to start with that February always has 28 days. Your program should check that both dates are valid and are supplied in the correct order.

Once the program is working, you could extend it to input the number of the year, work out if it is a leap year, and possibly update its record of the number of days in February.

6.4 String arrays and simple databases

Elsewhere we have introduced string variables and the use of such variables in simple string processing problems. More complex operations involving strings often require the use of arrays of strings. We have already met numeric arrays and string arrays are very similar. A string array is a list of strings all having the same name and referred to individually using a subscript notation. However, since strings can be of any length, up to 255 characters, the elements of a string array can be of unequal length. For example:



Realistic programs containing arrays of strings usually require vast amounts of data to initialise them. We may have, for example, a name and address list comprising thousands of entries and this must be the commonest use of string arrays in computers, judging by the amount of mail (junk and otherwise) that is addressed using computer printed addresses. Typical processing operations might be to extract from the list all those addresses containing the same postal code, or all those sharing the same town, etc. Systems like this that can be processed or interrogated are usually called databases. A database could be a simple list, or a series of lists, or the information may be structured in a particular way using combinations of arrays. How complex database structures are set up is outside the scope of this text, but we can look at very simple databases.

A simple database can be initialised by reading the contents of a file, usually from disk. Thus we may have, for example, in a department store, a stock database held on a large file. The data is read into the program data structure at 9 a.m., say, and then used all day long by operators. During the course of a day new information may be added to the database or existing information altered. Thus we may have a general program structure:

```
initialise data structures from file

REPEAT
   wait for information from user
   process information  from user
UNTIL endofday

write contents of data structure back
to file
```

We have already seen a simple example of this program structure in the last section. We will now look at how we can set up simple data structures involving string arrays. The next program uses an array of strings to store a list of names and addresses. We read information from a file into a single string array, carry out some processing and write the processed information into a new file.

```
10   DIM namelist$(100)
20   innames = OPENIN ("namefile")
30   FOR record = 1 TO 100
40     INPUT# innames, namelist$(record)
50   NEXT record
60   CLOSE# innames

70   outnames= OPENOUT ("extracted")
80   INPUT city$
90   FOR record = 1 TO 100
100    IF INSTR(namelist$(record), city$) <> 0
       THEN PRINT# outnames, namelist$(record)
110  NEXT record
120  CLOSE# outnames
```

(The string function INSTR is discussed fully in Chapter 8. It is used here to test whether the string that is its first parameter contains the string that is its second parameter.) In this simple program the writing and processing are carried out simultaneously. The next data structure is a little more complicated, consisting of four parallel arrays making up a stock control database. For example:

refno	name$	stock	priceof
157	screwdriver	352	3.75
163	hammer	27	5.62
175	spanner	31	1.35
181	axe	4	7.23
	:		

This is a simple example of a database. We may want to interrogate the database so that it prints out all the screwdrivers in stock:

```
refno. 157 (screwdriver) 352 in stock
refno. 239 (screwdriver)  28 in stock
refno. 575 (screwdriver)  37 in stock
```

Alternatively we may request the price of a certain item by giving the database a reference number:

```
The price of refno. 157 (screwdriver) is 3.75
```

We may want to give the database the information that a quantity of particular items have been sold. All these operations can be carried out easily on a simple data structure comprising four 'parallel' arrays as above. The array 'refno' could be either a numeric array or a string array depending on the operations that are to be carried out. The array 'name$' must be a string array and 'stock' and 'priceof' must be numeric arrays. Let's look at the first operation - printing out all the items belonging to a particular class, their associated reference numbers and the quantity in stock.

```
 10   DIM refno(100),name$(100),stock(100),priceof(100)
                    .
                    .
        Statements to initialise arrays from file
                    .
                    .
510   INPUT "Name of item", class$
520   FOR i = 1 TO sizeofstock
530     IF name$(i) = class$ THEN
          PRINT "refno "; refno(i); " (";
                name$(i);") "; stock(i); " in stock"
540   NEXT i
```

In order to give the price associated with a reference number we could use

```
610   INPUT "Stock number", number
620   i = 0
630   REPEAT
640     i = i + 1
650   UNTIL number = refno(i)
660   PRINT "Price of ref. no "; refno(i); " (";
                name$(i); ") is "; priceof(i)
```

To process an order and update the stock quantity:

```
710   INPUT "Stockno", number, "Quantity", quantity
720   i = 0
730   REPEAT
740     i = i + 1
750   UNTIL number = refno(i)
760   IF stock(i)-quantity<0 THEN
         PRINT "not enough in stock"
      ELSE  PRINT "Cost: "; quantity*priceof(i) :
            stock(i) = stock(i) - quantity
```

In the next chapter, we shall see how a section of program can be defined as a named 'procedure'. In a complete stock processing program, we would define each of the above sections of program as a named procedure and the main part of the program would organise the 'calling' of these procedures in response to requests from a user of the program. When the program recognises an 'out of stock' condition we could call another procedure that writes to a re-order file. In the next chapter, we shall revisit this example and see how to select such procedures using a standard 'menu selection' approach.

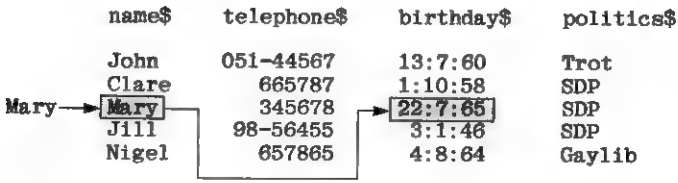
The next example uses four string arrays and also involves calculating element addresses. The program accesses a simple personal database. This is in the form of a string array containing friends' names and a set of corresponding arrays containing such attributes as, for example, date of birth, telephone number, political affiliations. The program accepts input in the form

```
Mary, birthday
```

and this causes an access via the name Mary to the corresponding element in the array storing birthdays. The appropriate output would be:

```
Mary's birthday is 22:7:65
```

The arrays and their contents might be:



The program is:

```
 10   DIM name$(100), telephone$(100), birthday$(100),
        politics$(100)
                .
                .
        initialise arrays from a file
                .
                .
 40   INPUT firstname$, attribute$
 50   i = 0
 60   REPEAT
 70     i = i + 1
 80   UNTIL name$(i) = firstname$
 90   position = i

100   IF LEFT$(attribute$,1) = "t" THEN
        PRINT firstname$; "'s "; attribute$;
                  " is "; telephone$(position)
110   IF LEFT$(attribute$,1) = "b" THEN
        PRINT firstname$; "'s "; attribute$;
                  " is "; birthday$(position)
120   IF LEFT$(attribute$,1) = "p" THEN
        PRINT firstname$; "'s "; attribute$;
                  " is "; politics$(position)
```

Note the use of LEFT$ in this program . This string function is covered in detail in Chapter 8. It is used here to examine the first letter of a string. The use of the function in this context means that the program will ignore spelling mistakes in the typing of 'attribute$' (but not 'firstname$'), providing the first character is not misspelt.

Exercises

1 Write a program that will input a list of names. The program is then to input a character and print out all these names from the list that begin with a specified character.

2 A tune can be stored in two parallel one-dimensional arrays 'pitch' and 'length' in which successive pairs of entries represent the notes of the tune in order. A variable 'numberofnotes' can be used to indicate how many notes there are in the tune. Write a program that can be used to help compose a tune. Commands that the program might recognise are:

"P" for Play the tune (and PRINT the arrays),
"N" for Next note (INPUT pitch and length),
"C" for Change note (INPUT note number, pitch and length),
"Q" for Quit.

3 Write a program that accepts as input four nouns, four verbs and four articles or demonstratives. The program should print ten random sentences. FOR example given input:

```
boy, girl, cat, dog
loves, eats, hits, bites
a, the, this, that
```

the output might be

```
this dog bites that girl
this girl eats this dog
the cat loves a girl
the boy eats the dog
```

6.5 Sorting lists into order

Sorting items in a list into some kind of order is a much used technique especially in data processing applications. We may want to sort a list of names into alphabetic order or to sort a list of reference numbers into increasing or decreasing numeric order.

Suppose we have a list 'refno', of unsorted reference numbers that we want to sort into increasing numerical order. If there are n of these numbers, then we should proceed:

```
Find the array element with the smallest number
Swap it with refno(1)

Find the array element with the second smallest number
(we need only now look from refno(2) onwards)
Swap it with refno(2)
                    .
                    .
                  etc.
```

in other words:

```
FOR i = 1 TO n - 1
    Find the element with the ith. smallest number
    Swap it with refno(i)
NEXT i
```

Filling in the details, the complete sort becomes:

```
110    FOR i = 1 TO n - 1
120      posnsmallest = i
130      FOR j = i + 1 TO n
140        IF refno(j) < refno(posnsmallest)
           THEN posnsmallest = j
150      NEXT j

160  REM **** now swap ****
170      temp = refno(i)
180      refno(i) = refno(posnsmallest)
190      refno(posnsmallest) = temp
200    NEXT i
```

This particular algorithm is called an exchange sort. Another common but perhaps less obvious technique is called 'bubble sorting'.

Exercises

1 Develop a complete program along the above lines to input a list of names and sort these into alphabetic order.

2 Can you generalise the numeric sorting program such that it will sort the numbers into either increasing or decreasing order according to a control inserted as input at the end of the list of numbers?

3 Write a program to input unsorted information into two parallel arrays. One array is to contain a list of names, the other a list of examination marks. A name and associated mark are of course in corresponding elements in each array. The program is to output a list of names and marks in decreasing mark order. Remember that when the position of a mark is changed, the position of the associated name must also be changed.

6.6 Two-dimensional arrays

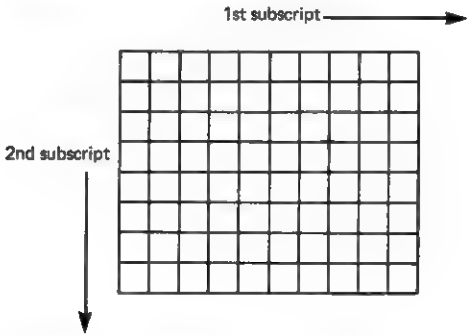
Many techniques in science, engineering and commerce deal with data that is organised in two dimensions. Pictures from interplanetary explorers, for example, are enhanced and analysed by computer. The pictures are represented inside the computer as a two-dimensional table of numbers. Each number corresponds to the brightness of a picture element or point. A picture is converted into a table of numbers by a special input device, and after it is processed it is converted back into a picture by a special output device. It is much easier and more natural for a programmer to think in terms of a two-dimensional set of picture elements - the picture retaining its two-dimensional form when referred to in the program - than it would be if the picture elements

were strung out row-wise or column-wise into a one-dimensional array or list.

Consider another example - a 10x8 table of numbers (10 columns, 8 rows), where each number represents the population of the corresponding zone of a 10x8 square mile map. We can retain the two-dimensional nature of the data by storing it in a two-dimensional array 'popmap'. First of all let us see how we tell the computer we are going to use such a structure.

```
DIM popmap(10, 8)
```

This declaration has set up a two-dimensional structure into which we can place the data. We can picture a two-dimensional array as a collection of variables, all of the same type, organised into columns and rows.



The first subscript determines a column and the second subscript determines a row. For example 'popmap(3,7)' refers to the location in the 3rd column and the 7th row of the array. Thus we picture the declared array as corresponding in size and shape to to the table of data that we are considering. Actually the two subscripts will run from zero upwards - the computer sets aside space for row zero and column zero. However, it is convenient to ignore row zero and column zero just as we ignored element zero in one-dimensional arrays.

An interesting point to note is that we could equally well visualise the array the other way round, ie. with the first subscript representing a row number and the second a column. In many mathematical applications involving matrix algebra, this alternative picture would correspond to mathematical conventions. It does not matter how we picture our two-dimensional arrays as long as we are consistent.

On the Electron computer, we are used to using x-y coordinates to describe positions on the screen and it will be less confusing if we picture our two-dimensional arrays

as having the same structure as the screen.

To do something systematically with all the locations of a two-dimensional array, we need to use a nested FOR-statement. For example, if we wish to deal with the array a row at a time we need the outline structure:

```
FOR row = 1 TO 8
    deal with row
```

and dealing with a row involves a further loop:

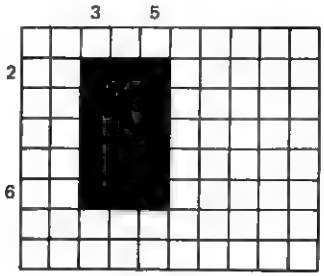
```
FOR column = 1 TO 10
    deal with the location popmap(column, row)
```

The next example illustrates this. The program inputs the population table described above, stores it in a suitable array, calculates the total population and prints a copy of the population table. The program would, in practice, input from a file, but we omit the extra details to keep things simple.

```
 10   DIM popmap(10, 8)
 20   FOR row = 1 TO 8
 30     FOR column = 1 TO 10
 40       INPUT popmap(column, row)
 50     NEXT column
 60   NEXT row

 70   total = 0
 80   FOR row = 1 TO 8
 90       FOR column = 1 TO 10
100       total = total + popmap(column, row)
110       NEXT column
120   NEXT row
130   PRINT "Total population is "; total

135   @% = &0404
140   PRINT "Populations of individual zones are:"
150   FOR row = 1 TO 8
160     FOR column = 1 TO 10
170       PRINT popmap(column, row);
180     NEXT column
185     PRINT      :REM start a new line for next row.
190   NEXT row
195   @% = &0A0A
```

The formatting statement at line 135 has the effect of dividing the screen into 4-character fields so that 10 numbers will fit on one line (see Appendix 6). The first nested FOR loop causes the data to be read into the two-dimensional array 'popmap', the second accesses the array, performing the required calculation, and the third causes the contents of the array to be printed. When the input for this program is being typed, the 10 numbers in the first row of the table are typed first and these are stored in the first row of the array. Then the 10 numbers in the second row are typed, and so on. Incidentally, the processes of reading the data and accumulating the total could have been carried out simultaneously, the first two nested loops being merged into a single nested loop. This could not be easily done in the next program.

The next program inputs a population table. In addition it inputs four numbers defining a sub-region on the map over which the population is to be added. For example, input of 3, 5, 2, 6 specifies the region lying between columns 3 and 5 and between rows 2 and 6:




```
 10   DIM popmap(10, 8)
 20   FOR row = 1 TO 8
 30     FOR col = 1 TO 10
 40       INPUT popmap(col, row)
 50     NEXT col
 60   NEXT row

 70   subtotal = 0
 80   INPUT cola, colb, rowa, rowb
 90   FOR row = rowa TO rowb
100     FOR col = cola TO colb
110       subtotal = subtotal + popmap(col, row)
120     NEXT col
130   NEXT row

140   PRINT "Population of sub-zone is "; subtotal
```

The next program reads in the population table and finds every zone with a population less than half the average of its north, south, east and west neighbours.

```
 10   DIM popmap(10, 8)
 20   FOR row = 1 TO 8
 30     FOR col = 1 TO 10
 40       INPUT popmap(col, row)
 50     NEXT col
 60   NEXT row

 70   FOR row = 2 TO 7
 80     FOR col = 2 TO 9
 90       average = (popmap(col,row-1)
                    +popmap(col,row+1)
                    +popmap(col-1,row)
                    +popmap(col+1,row))/4
100       IF popmap(col,row) < average/2 THEN
              PRINT "Region "; col; ","; row;
                                " is underpopulated."
110     NEXT col
120   NEXT row
```

The next program illustrates random access to a two-dimensional array.

A student's week is divided up into 5 days, each of 6 periods numbered 1 to 6. He must attend 20 lectures during each week. The program inputs a list of his lecture times and places. Each lecture time is represented by two integers giving the day (1 to 5) and the period (1 to 6) and these two integers are followed by the number of the room (a positive integer) in which the lecture takes place.

The program prints a timetable for the student in the form:

		Mon	Tue	Wed	Thu	Fri
	1	3	6		5	3
	2	1	6	2	2	2
period	3	2	5	1	5	1
	4	9	7			3
	5		6		8	
	6			7		

where the entry for each period represents the room number in which he should be. We assume that the input data is such that there are no timetable clashes.

```
 10   DIM place(5, 6)
 20   REM  *** mark all periods as free ***
 30   FOR day = 1 TO 5
 40    FOR period = 1 TO 6
 50       place(day, period) = 0
 60    NEXT period
 70   NEXT day

 80   REM ** fill appropriate periods with room number **
 90   FOR lecture = 1 TO 20
100     INPUT day, period, room
120     place(day, period) = room
130   NEXT lecture

140   REM ** print timetable **
150   PRINT "             Mon  Tue  Wed  Thu  Fri"
160   PRINT "             ----------------------"
170   @% = &0505          :REM  see Appendix 6
180   FOR period = 1 TO 6
190      IF period = 3 THEN PRINT "period  ";
                       ELSE PRINT "        ";
200      PRINT ; period;
210      FOR day = 1 TO 5
220        IF place(day, period) = 0 THEN PRINT "     ";
           ELSE PRINT place(day, period);
230      NEXT day
240      PRINT
250   NEXT period
260   @% = &0A0A
```

Exercises

1 You may prefer to have your timetable displayed in the form

```
                period

          1   2   3   4   5   6
          ----------------------
Mon       3   1   2   9
Tue       6   6   5   7   6
Wed           2   1
Thu       5   2   5       8   7
Fri       3   2   1   3
```

Rearrange the second half of the last program so that it does this. You will need to reverse the order of nesting of the FOR loops, and use an ON-GOTO statement to print the name of a day of the week.

2 In a warehouse system, car parts are stored in a two-dimensional stack of pigeonholes, thirty columns long and

ten rows high. This unit is accessed by an automatic electromechanical fetch unit that is given a pair of coordinates by a computer when a part is to be fetched. The values of the elements of a two-dimensional array are to represent the number of items in the pigeonholes and this array should be initialised from a file.

Write a program that repeatedly:

(a) accepts a reference number in the range 1 to 300 and outputs the corresponding pair of coordinates (successive reference numbers are to correspond to consecutive pigeon holes in a row-wise manner starting at the top left pigeonhole);

(b) decrements the appropriate array location by one, thus keeping an up-to-date stock record;

(c) writes an appropriate message if the stock in a pigeonhole falls below ten items.

The input reference numbers will be terminated by two negative numbers. At this point the program should print a two-dimensional representation of the stack, printing a '-' for the pigeonholes in which the stock has fallen below ten items and printing a '+' for the others.

Chapter 7 Procedures and functions

A procedure is a section of program to which a name has been given. The programmer can then write the name of the procedure wherever he wants that section of program to be obeyed. This has two main advantages.

Firstly, if the named operation has to be carried out at several different places in a large program, we avoid writing out the same section of program in full at each place.

Secondly, and just as important, careful use of procedures can make a large program easier to write and easier for other people to read. For example, in a payroll program we might require a sequence of operations such as

```
add normal hours pay
add overtime hours pay
deduct income tax.
```

Defining a BASIC procedure for each operation allows us to write the sequence of BASIC statements:

```
10  PROCaddnormalhourspay
20  PROCaddovertimehourspay
30  PROCdeductincometax
```

where the details of each named operation are defined elsewhere. This makes it much easier to understand what the program is doing than it would be if the details for each calculation were simply written out in full.

7.1 Introductory example

To demonstrate how to define and use a BASIC procedure, we shall write a very simple program that accepts input of a greeting and a name and displays a personalised greeting in the centre of the screen. Of course this program could be written without procedures (in fact it was set as an exercise in Chapter 1), but we shall use it as an introductory example.

In our program, we shall define two separate procedures, one to organise the input and the other to display the greeting. The first two lines of the program will tell the computer what we want done by simply writing the names of

the two procedures that are to be obeyed:

```
10   PROCgetinput
20   PROCdisplaygreeting
```

The details of how to 'getinput' must of course be described. So must the details of how to 'displaygreeting'. The complete program is:

```
 10   PROCgetinput
 20   PROCdisplaygreeting
 30   END

100   DEF PROCgetinput
110     INPUT "Message:" message$
120     INPUT "Name of recipient:" name$
130   ENDPROC

200   DEF PROCdisplaygreeting
210     CLS
220     PRINT TAB(5,9);  "************************"
230     PRINT TAB(10,11); message$
240     PRINT TAB(14,13); name$
250     PRINT TAB(5,15); "************************"
260   ENDPROC
```

When the program is obeyed, the first statement encountered is at line 10. This statement is known as a 'procedure call' and tells the computer to go and obey the procedure with the name PROCgetinput. The definition of this procedure lies between lines 100 and 130. When the computer is told to obey a procedure, it finds the procedure heading (line 100 in this case) and obeys the subsequent instructions. When it encounters an ENDPROC statement, it returns to the statement that told it to obey the procedure and carries on from there. In this case, when the computer has obeyed PROCgetinput, it returns and carries on from line 20. This statement tells it to obey the statements that make up the definition of PROCdisplaygreeting (lines 200 to 260). Once this has been done, control returns to the line that called the procedure. Line 30 then tells the computer to do nothing further. The END statement at line 30 is needed to stop the computer from attempting to obey PROCgetinput again. The large gaps in the line numbering between lines 35 and 100 are not strictly necessary, but leaving such gaps makes it easier to extend a program without having to renumber it.

The same procedures could have been called as often as we liked from the main part of the program. For example, let us change the program so that it leaves a greeting displayed until someone hits a key, upon which it accepts more input and displays a new greeting. We replace lines 10 to 30 with:

```
10   PROCgetinput
20   PROCdisplaygreeting
30   key = GET
40   PROCgetinput
50   PROCdisplaygreeting
60   END
```

The rest of the program remains as before. PROCgetinput is now used twice in the main part of the program, but the details are written only once in the procedure definition. The same applies to PROCdisplaygreeting.

Another possibility would be to replace lines 10 to 60 with the following:

```
10   REPEAT
20     PROCgetinput
30     PROCdisplaygreeting
40     key$ = GET$
50   UNTIL key$ = "Q"

60   END
```

The procedure definitions again remain as before. This version of the program repeats the process of input and display every time a key is pressed, stopping when someone types Q.

7.2 Procedures and stepwise refinement

In Chapter 5, we presented informally the well-known programming method called 'stepwise refinement'. The first step in writing a complex program should be to sketch an outline of what the program is going to do without getting bogged down in the detailed BASIC instructions required. Using procedures for the logically distinct operations in a program allows us to write our initial outline in BASIC where we invent procedure names to describe operations that we have not yet programmed in detail. Only when we have a clear idea of what each named procedure is to do and how it fits into the overall program do we go on to define each procedure in detail.

In a complicated program, writing one of the procedures may itself be a difficult programming task and a procedure can itself be defined in terms of other procedures.

We illustrate this approach to programming by writing a program that plays a simple guessing game. The computer makes up a random number between 1 and 100 and the user seated at the keyboard must attempt to guess the number. For each wrong guess, the computer tells the user whether the guess was too high or too low and the process terminates

when the number is guessed correctly. The program finishes by analysing and commenting on the player's performance.

We start by outlining the process that the program will carry out:

```
10   PROCinitialise
20   REPEAT
30     PROCtryguess
40   UNTIL gotit

50   PROCanalyseperformance
60   END
```

PROCinitialise will set the variables required by the program to their starting values. Each call of PROCtryguess will input the player's next guess and test it against the secret number (invented by PROCinitialise). PROCanalyseperformance will report how many attempts were needed to guess the number and will print an appropriate message.

PROCinitialise and PROCtryguess are defined as:

```
100   DEF PROCinitialise
110     secretnumber = RND(100)
120     tries = 0
130     gotit = FALSE
140   ENDPROC

200   DEF PROCtryguess
210   LOCAL guess
220     tries = tries + 1
230     INPUT "Guess:" guess
240     IF guess = secretnumber THEN
            gotit = TRUE : ENDPROC
250     IF guess < secretnumber THEN
              PRINT "Too small!";
        ELSE  PRINT "Too big!";
260     PRINT " Try again.";
270   ENDPROC
```

In PROCtryguess, we have specified at line 210 that the variable 'guess' is 'local' to the procedure. This variable is available for use only while PROCtryguess is being obeyed. Variables declared at the start of a procedure in this way can not be used after ENDPROC has been obeyed. It is recommended that any variable which is used only within a particular procedure should be declared locally to that procedure. The computer will then ensure that the programmer does not accidentally use the same variable for conflicting

purposes in different parts of a large program. If a variable with the same name is used elsewhere in the program, its value will automatically be held in a different storage location, thus eliminating any possibility of conflict.

When PROCtryguess is obeyed, the first test that it makes at line 240 is to decide whether the player has guessed the secret number. If he has, then 'gotit' is set to true and an ENDPROC statement is obeyed immediately. This terminates the procedure and lines 250 to 270 are ignored. If the player has not guessed correctly, the ENDPROC at line 240 is ignored and the computer carries on to obey lines 250 and 260 before encountering the ENDPROC at line 270. The extra ENDPROC at line 240 has been used to create the effect of a complex IF-THEN-ELSE statement where the 'ELSE part' occupies more than one numbered line.

Finally, we define PROCanalyseperformance:

```
300   DEF PROCanalyseperformance
310     PRINT "That took "; tries; " attempts."
320     IF tries <= 7 THEN  PRINT "Very good!"
        ELSE PRINT "You need to improve your strategy."
330   ENDPROC
```

As your programs become more complicated, you should try to adopt the approach illustrated above. Any logically separate section of program should be defined as a procedure and given a descriptive name. In practice, writing a lot of procedures of only two or three lines, like PROCinitialise, might be considered excessive. In such cases, we leave it to you to find a compromise that suits you.

7.3 Menu selection

In this section we return to the fragments of a stock control program that were presented in Section 6.4. We now present a program in which the the various stock control operations are defined as procedures and a menu selection procedure is used to determine which operation is to be carried out next.

```
10   DIM refno(100),name$(100),stock(100),priceof(100)
20   PROCinitialise
30   PROCprintmenu
40   REPEAT
50     INPUT command$
60     PROCmenuselect
70   UNTIL command$ = "F"
80   PROCcreatenewstockfile
90   END
```

```
100   DEF PROCinitialise
        *** defined in Appendix 2 ***
180   ENDPROC

200   DEF PROCcreatenewstockfile
        *** defined in Appendix 2 ***
280   ENDPROC

300   DEF PROCprintmenu
310     PRINT:PRINT
320     PRINT "Type M for menu"
330     PRINT "Type S for stock enquiry"
340     PRINT "Type P for price enquiry"
350     PRINT "Type O to process order"
360     PRINT "Type F to finish and file stock list"
370     PRINT:PRINT
380   ENDPROC

400   DEF PROCmenuselect
410     IF command$ = "M" THEN PROCprintmenu
420     IF command$ = "S" THEN PROCprintitemsinclass
430     IF command$ = "P" THEN PROCfindprice
440     IF command$ = "O" THEN PROCprocessorder
450   ENDPROC

500   DEF PROCprintitemsinclass
510     INPUT "Name of item", class$
520     FOR i = 1 TO sizeofstock
530       IF name$(i) = class$ THEN
            PRINT "refno "; refno(i); " (";
                  name$(i);") "; stock(i); " in stock"
540     NEXT i
550   ENDPROC

600   DEF PROCfindprice
610     INPUT "Stock number", number
620     i = 0
630     REPEAT
640       i = i + 1
650     UNTIL number = refno(i)
660     PRINT "Price of ref. no "; refno(i); " (";
                  name$(i); ") is "; priceof(i)
670   ENDPROC
```

```
700   DEF PROCprocessorder
710   INPUT "Stockno", number, "Quantity", quantity
720     i = 0
730     REPEAT
740       i = i + 1
750     UNTIL number = refno(i)
760     IF stock(i)-quantity<0 THEN
           PRINT "not enough in stock"
        ELSE  PRINT "Cost: "; quantity * priceof(i) :
              stock(i) = stock(i) - quantity
770   ENDPROC
```

There are, of course, many more options that could be added to this program. These are left as exercises.

7.4 Data validation

When it is possible to check or validate the information input to a program this should always be done. Not only does this guard against the possibility of a run-time error, the cause of which might not be immediately apparent to the user, but worse - invalid data may cause erroneous results which go unnoticed. The use of procedures can make it easier to incorporate such tests in the design of a program. In simple cases, we can use a structure such as:

```
INPUT information

IF information is ok THEN
      obey main part of program
       (defined as a procedure)
ELSE  PRINT error message
```

The next program uses this structure. It calculates the cost of a holiday by multiplying the duration in days by a daily rate that is seasonally variable. The input consists of two dates each in the form day, month. We assume that the months will be either identical or consecutive. Also, we assume that it is the second month which determines the seasonal rate. We have somewhat simplified the checks for the purposes of this demonstration - not every month has 31 days and we have not catered for numbers <=0.

The use of the procedure PROCholidaycost not only makes clear the structure of the program. It also overcomes the restriction on the number of statements that we can have between THEN and ELSE. It is also convenient to define a separate procedure for working out the duration of the holiday.

```
10   lowrate = 57
20   midrate = 72
30   peakrate= 87
40   INPUT day1, month1, day2, month2
50   IF day1 <= 31 AND day2 <= 31 AND month2 <= 12 AND
       ((month1 = month2 AND day1 < day2)
           OR (month2 = month1+1))
     THEN PROCholidaycost
     ELSE PRINT "You have typed erroneous dates."
60   END

100  DEF PROCholidaycost
110    PROCworkoutduration
120    ON month2 GOTO 121, 121, 122, 122, 122, 123,
                      123, 123, 123, 122, 121, 121
121      cost = duration * lowrate  : GOTO 130
122      cost = duration * midrate  : GOTO 130
123      cost = duration * peakrate
130    PRINT "Cost of holiday is "; cost
140  ENDPROC

200  DEF PROCworkoutduration
210    IF month1 = month2 THEN
           duration = day2 - day1 + 1 : ENDPROC
220    ON month1 GOTO 223, 221, 223, 222, 223, 222,
                      223, 223, 222, 223, 222, 223
221      tillendofmonth = 28 - day1 : GOTO 230
222      tillendofmonth = 30 - day1 : GOTO 230
223      tillendofmonth = 31 - day1
230    duration = tillendofmonth + 1 + day2
240  ENDPROC
```

In the above program, PROCholidaycost is obeyed only if the input is acceptable (within the limits of the test used). If the input is erroneous, the user will have to RUN the program again. If a program is required to automatically request more input until a correct set of values are typed, then the following structure can be used:

```
REPEAT
   INPUT information
   inputok = result of test on input
   IF NOT inputok THEN
        PRINT "Error! please retype information."
UNTIL inputok
```

obey main part of program

In the case of the holiday program, use of this structure would give:

```
10   lowrate = 57
20   midrate = 72
30   peakrate= 87

40   REPEAT
50     INPUT day1, month1, day2, month2
60     inputok = day1<=31 AND day2<=31 AND month2<=12 AND
                 ((month1=month2 AND day1<day2)
                  OR (month2=month1+1))
70     IF NOT inputok THEN
         PRINT "Erroneous dates. Please retype."
80   UNTIL inputok

90   PROCholidaycost
95   END
```

Exercises

1 A company's employees are paid £4.85 per hour for a standard 35 hour week. Overtime hours during the week are paid at 1.25 times this basic rate and overtime hours at the weekend are paid at 1.5 times this rate. Income tax is paid at the rate of 30% on the first 100 pounds of a week's pay, 40% on the next 100 pounds and 50% on the remainder. Write a program that accepts, as input, the number of weekday overtime hours worked by an employee in one week. The program should display a payslip giving details of his normal pay, overtime pay and deductions for that week. The main part of the program should consist of the three procedure calls presented in the introduction to this chapter.

2 Rewrite the computer-assisted learning program presented at the end of Chapter 5, but use a procedure so that the main part of the program becomes:

```
REPEAT
   PROCsetproblem
   INPUT "More? Y/N:" reply$
UNTIL reply$ = "N"
```

3 Rewrite some of the other programs of Chapter 5 using procedures, as in Exercise 1 above, to make clear the logical structure of the program.

4 In order to run the stock control program for the first time, a stock file will have to be set up. Write a separate program to do this.

5 Extend the stock control program to include an 'Update stock level' command. After typing this command, the user will type a reference number and a quantity that is to be added to the previous stock level for that item.

6 Extend the stock control program to include a 'Check stock level' command. This command should list all those items for which the number in stock is less than 10.

7 Extend the holiday booking program to include complete data validation. One neat way of doing this is to set up an array of 12 locations, one for each month. Each location should contain the number of days in the month. The number of days in February will depend on the year which will have to be supplied as additional input. The values in this array can then be used in testing the validity of a day.

7.5 Parameters

We have seen how simple procedures can be used to enable a program to carry out the same operation at different points in a program. A common requirement is for similar, but not necessarily identical, operations to be carried out at different points in a program.

For example, in Chapter 2, we wrote a program that worked out how many coins of each denomination were needed to make up a given amount of change. The operation used to calculate the number of 50p pieces to be included in the change was very similar to the operation used for each of the other coin denominations. We can reprogram this process using a procedure:

```
10   INPUT "Change", change

20   PROChowmany(50) :  PROChowmany(20)
30   PROChowmany(10) :  PROChowmany( 5)
40   PROChowmany( 2) :  PROChowmany( 1)
```

The intention here is that PROChowmany is the name of a procedure that is going to be used six times. Each time the procedure is called, it is supplied with a 'parameter' in brackets telling it which denomination of coin to deal with next. The complete program is:

```
10   INPUT "Change", change

20   PROChowmany(50) :  PROChowmany(20)
30   PROChowmany(10) :  PROChowmany( 5)
40   PROChowmany( 2) :  PROChowmany( 1)
50   END

100  DEF PROChowmany(denomination)
110  LOCAL noofcoins
120    noofcoins = change DIV denomination
130    change = change MOD denomination
140    PRINT "No of "; denomination; "s "; noofcoins
150  ENDPROC
```

In the procedure definition, the operation to be carried out by the procedure is specified in terms of 'denomination', which is a parameter. When the procedure is called, this parameter is given an actual value which is to be used when the procedure is obeyed. Thus, obeying the statement

```
PROChowmany(50)
```

causes the procedure definition to be obeyed with:

```
denomination = 50
```

Similarly, obeying the statement

```
PROChowmany(20)
```

causes the procedure to be obeyed with:

```
denomination = 20
```

A parameter supplied in brackets when the procedure is called is usually referred to as an 'actual parameter'.

A procedure with parameters will perform some general task defined in terms of these parameters. When the parameters are given actual values, the procedure performs a particular version of the general task. Such a facility is extremely important in modern programming.

The next procedure is defined in terms of two parameters.

```
100  DEF PROCtabulate(x, n)
110  LOCAL i
120    PRINT "Table of multiples of "; x  :  PRINT
130    FOR i = 1 TO n
140       PRINT i * x
150    NEXT i
160    PRINT
170  ENDPROC
```

When this procedure is called, multiples of the number supplied as its first parameter are printed, the number of multiples being specified as a value for the second parameter. If we call this procedure:

```
10   PROCtabulate(3.72, 4)
```

'x' is given the value 3.72, 'n' is given the value 4 and the procedure definition is obeyed. Output is therefore:

```
Table of multiples of 3.72

      3.72
      7.44
     11.16
     14.88
```

The actual parameters supplied to this procedure can in fact be any two expressions. For example, the fragment:

```
10   r = 4.3 : noofmultiples = 5
20   PROCtabulate(r, noofmultiples)
30   PROCtabulate(SQR(SQR(r)), 2*noofmultiples)
40   END
```

will tabulate the first 5 multiples of 4.3 and the first 10 multiples of the fourth root of 4.3.
The fragment:

```
10   DIM a(4)
20   FOR i = 1 TO 4 : INPUT a(i) : NEXT i

30   FOR i = 1 TO 4
40     PROCtabulate(a(i), 10)
50   NEXT i
60   END
```

will call the procedure 4 times and output 4 tables, one for each entry in the array 'a'.

In other programming languages, it is usually possible to pass information out of a procedure by changing the value of one of its parameters while the procedure is being obeyed. In Electron BASIC, parameters can only be used for passing information into a procedure and these parameters are sometimes known as input parameters. If information calculated in a procedure is to be used outside that procedure, the information must be placed in a global variable - any variable that is not a parameter or a local variable. For example, in the program at the beginning of

this section the global variable 'change' is altered by each call of the procedure. In fact this global variable is used both to transfer information into and out of the procedure.

As we mentioned earlier, a procedure definition can include calls of other procedures. The next program reads two positive integers and prints them in descending order. The integers are to be output on separate lines and, when an integer is output, the millions are to be followed by a comma and the thousands are to be followed by a comma. Thus, instead of printing 5674251 the program should print 5,671,251

```
10   INPUT first, second
20   IF first > second THEN
        PROCcommaprint(first) : PROCcommaprint(second)
     ELSE
        PROCcommaprint(second) : PROCcommaprint(first)
30   END

100   DEF PROCcommaprint(n)
110   LOCAL millions, thousands, units
120     millions = n DIV 1000000
130     thousands = (n MOD 1000000) DIV 1000
140     units = n MOD 1000
150     IF millions > 0 THEN
           PRINT ;millions; ","; :
           PROCzeroprint(thousands) : PRINT ","; :
           PROCzeroprint(units) : PRINT :
        ENDPROC
160     IF thousands > 0 THEN
              PRINT ;thousands; ","; :
              PROCzeroprint(units) : PRINT :
        ENDPROC
170     PRINT ;units
180   ENDPROC

200   DEF PROCzeroprint(m)
210     IF m < 100 THEN PRINT "0";
220     IF m < 10  THEN PRINT "0";
230     PRINT ;m;  :REM  See Appendix 6
240   ENDPROC
```

Writing the main part of this program (lines 10 to 30) is straightforward, provided that we avoid getting bogged down in the problems involved in printing a number with the commas inserted. Designing PROCcommaprint can then be viewed as a programming problem which is slightly easier than the original problem. The need for PROCzeroprint arises because, for example, a number of thousands has to be written with a full three digits in the context of a number like 2,067,003. In the number 67,003 the thousands are printed with no extra

zeros, and a normal PRINT statement is used.

7.6 String parameters

The parameter of a procedure can be a string. For example, the following program displays a message surrounded by stars in the centre of the screen, pauses for 5 seconds, displays a second message, and clears the screen after a further 10 seconds.

```
 10   PROCdisplay("Merry", "Christmas")
 20   PROCtimedelay(500)
 30   PROCdisplay("Happy", "New  Year")
 40   PROCtimedelay(1000)
 50   CLS : END

100   DEF PROCdisplay(line1$, line2$)
110   LOCAL r
120     CLS
130     PRINT TAB(13,9);  "**********"
140     FOR r = 10 TO 14
150       PRINT TAB(13,r); "*"; TAB(25,r); "*"
160     NEXT r
170     PRINT TAB(13,15); "**********"

180     PRINT TAB(17,11); line1$
190     PRINT TAB(15,13); line2$
200   ENDPROC

300   DEF PROCtimedelay(d)
310   LOCAL stoptime
320     stoptime = TIME + d
330     REPEAT : UNTIL TIME > stoptime
340   ENDPROC
```

PROCdisplayboard is defined in terms of two parameters that are both strings. The first time it is called (at line 10), we have

```
line1$ = "Merry"
line2$ = "Christmas"
```

The second time it is called (at line 30), we have

```
line1$ = "Happy"
line2$ = "New  Year"
```

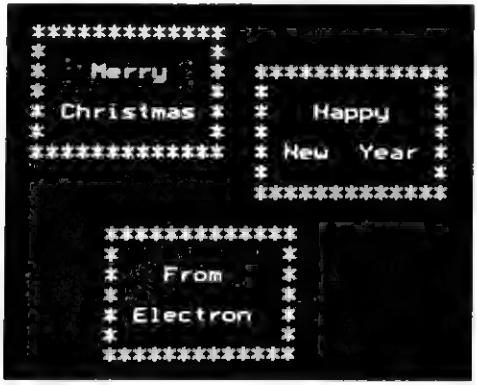
PROCdisplay could also have been supplied with string variables as its actual parameters. For example, we could write:

```
10   INPUT "Message, part1:" part1$
20   INPUT "         part2:" part2$
30   PROCdisplay(part1$, part2$)
40   END
```

In the above program, PROCtimedelay has been defined in such a way that the BASIC variable TIME is left unchanged. This mechanism will be useful in applications where a time delay is required, but where TIME is also being used for other purposes.

Procedures can have any combination of numeric and string parameters. In the next program, we have extended PROCdisplay so that it requires two additional parameters telling it where on the screen to display the message. It is used to display three messages on different parts of the screen simultaneously.

```
 10   CLS
 20   PROCdisplay(5,  5, "Merry", "Christmas")
 30   PROCdisplay(20, 7, "Happy", "New  Year")
 40   PROCdisplay(10,15, "From",  "Electron")
 50   END

100   DEF PROCdisplay(col, row, line1$, line2$)
110   LOCAL r
120     PRINT TAB(col,row); "************"
130     FOR r = row + 1 TO row + 5
140       PRINT TAB(col, r); "*"; TAB(col+12, r); "*"
150     NEXT r
160     PRINT TAB(col, row + 6); "************"
170     PRINT TAB(col + 4, row + 2); line1$
180     PRINT TAB(col + 2, row + 4); line2$
190   ENDPROC
```



Exercises

1 Write a program that accepts three sums of money, each input as a real number of pounds. The program should tabulate the three sums of money in two columns, one column for the pounds and one for the pence. The program should add up the three sums of money and print the total at the bottom of the two columns. Use a procedure, PROCprintmoney, that takes a real number of pounds as its parameter and prints it as two integers, pounds and pence.

2 Write a program that draws a selection of circles with different centres and different radii. The program should use a procedure:

```
PROCcircle(centrex, centrey, radius)
```

(A program for drawing a single circle appeared in Chapter 4.)

3 Write a program that plays a simple tune and then plays it again in a different key. Use a procedure:

```
PROCplaytune(key)
```

where the parameter indicates the pitch of the keynote.

4 Write a program that displays several Christmas trees, each outlined in stars and containing the message "Merry Christmas" followed by someone's name. Use a procedure to print a Christmas tree in a specified position and containing a specified name:

```
PROCchristmas(row, column, name$)
```

7.7 Functions

If the result of some process is a single value, then a function is sometimes an elegant alternative to a procedure. We have already seen how to use the standard functions SQR, SIN, COS and so on and we will now look at how to write our own functions.

First let us look at the ways in which a function differs from a procedure. Certainly, they are both separate modules of program text referred to by name, but they differ in the way in which they are called. Functions are called by using them in arithmetic expressions - that is the first difference. The second difference is that the result of obeying the function is a single value which replaces the function call in the originating expression. Let us illustrate this by considering:

```
y = x + SQR(2)
```

When this statement is being obeyed, the computer obeys the definition of the standard function SQR, and a number - the result of obeying the function - replaces the subexpression SQR(2). In the case of a standard function like SQR, the definition of the function is already stored as part of the BASIC system, but it is also possible for the programmer to define his own functions. In Electron BASIC, a programmer defines a function in a way that is very similar to the way in which procedures are defined. A function defined in this way can be used in exactly the same way as the standard functions.

This program reads 3 pairs of numbers and adds the larger of the first pair, the larger of the second pair and the larger of the third pair. A function is used to find the larger of two numbers.

```
10   INPUT a,b, p,q, x,y
20   PRINT FNmax(a,b) + FNmax(p,q) + FNmax(x,y)
30   END

40   DEF FNmax(first,second)
50      IF first > second THEN  = first
        ELSE  = second
```

The effect of calling a function is the calculation of a single result. Since calling a function produces a single result, we must indicate, somewhere in the function definition, what this result is to be. Instead of ENDPROC, the function terminates when a statement of the form:

```
= expression
```

is obeyed. The value of this expression is returned as the value of the subexpression used to call the function. Apart from this need to return a value as its result, the definition of the function can include as many statements as are necessary to calculate this value.

When the above program is obeyed, evaluation of the subexpression 'FNmax(a,b)' causes the function definition to be obeyed with 'first' set to the value of 'a' and 'second' set to the value of 'b'. If the function is called when we have the situation

```
a = 4.79
b = 5.64
```

then the function definition is obeyed with

```
first = 4.79
second = 5.64
```

and the statement

```
= second
```

is obeyed as a result of obeying the IF statement. The value of the subexpression 'FNmax(a,b)' is therefore 5.64 and this is the value used in subsequent evaluation of the larger expression:

```
FNmax(a,b) + FNmax(p,q) + FNmax(x,y)
```

If the main part of the program had included a statement such as

```
PRINT FNmax(63.45, 61.23)
```

the function would have been obeyed with

```
first = 63.45
second = 61.23
```

and the value returned as the result of the function in this case would be 63.45, this value being displayed by the PRINT statement. The actual parameters can of course be any expressions that will have numeric values when the program is obeyed. This means that the actual parameters in a call of the function can themselves involve further function calls. We have already seen how we can do this with the standard functions:

```
z = SQR(SQR(x) + SQR(y))
PRINT SQR(SQR(SQR(z)))
```

FNmax can be used in the same way:

```
PRINT FNmax(SQR(2), SQR(3))
```

will print

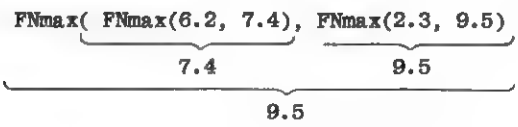
1.73

```
PRINT FNmax( FNmax(6.2, 7.4), FNmax(2.3, 9.5) )
```

will print

9.5

In the last case, the function calls are evaluated as:



As another example, the last program could have been written (rather longwindedly) as:

```
10   INPUT a,b, p,q, x,y
20   PRINT FNsumof(FNmax(a,b), FNmax(p,q), FNmax(x,y))
30   END

40   DEF FNmax(first,second)
50      IF first > second THEN  = first
        ELSE  = second

60   DEF FNsumof(n1, n2, n3)
70   = n1 + n2 + n3
```

Exercises

1 Write a program that inputs two pairs of marks and outputs the average of the first pair of marks followed by the average of the second pair of marks. The program should use a function, FNaverage to calculate the average of two marks.

2 A motor rally takes place on one day and, for each car, a start time and a finish time are recorded. Each car also has a handicap time which is to be subtracted from the true time taken for the rally in order to determine an adjusted time. Write a program which reads the start time, finish time and handicap time for one car and which prints the true time and the adjusted time for that car. Each time is input as two integers (hours and minutes) separated by a space. The program should do all its calculations in minutes, the conversion from hours and minutes being done by a function, FNinputtime, that can be used by, for example:

```
start = FNinputtime
```

The conversion back to hours and minutes should be done by a procedure PROCprinttime which takes a parameter representing a time in minutes and prints it in hours and minutes.

7.8 A final example - a noughts and crosses program

In this section, as a final example on the use of procedures and functions, we shall develop a program that is much more complicated than any that we have written so far. We shall write a program that plays a game of 'noughts and crosses' (tic-tac-toe) with an opponent seated at the keyboard. The program will make extensive use of procedures and functions, partly to assist us in the program design process and partly to save us from writing similar pieces of program in several different places. The main part of the program is:

```
10   PROCstartgame
20   PROCdisplayboard

30   REPEAT
40     IF computersturn THEN PROCcomputer
                         ELSE PROCopponent
50     PROCdisplayboard
60     PROCtestgameover
70   UNTIL gameover
80   PROCannouncewinner
90   END
```

In this outline, we have not yet committed ourselves to any details about the game. Indeed, we have not yet committed ourselves to the game of noughts and crosses. The same outline structure could be used for any board game such as draughts (checkers) or chess. However, the correct logical structure for playing a board game is established, breaking the task into logically distinct modules, each one of which is considerably easier to cope with than the whole problem.

All the details of how to start the game off by setting variables to their initial values and deciding who starts will appear in PROCstartgame. Before we can define this procedure, we must decide on how to represent the 'board'. Each square on the noughts and crosses board can contain an "X", an "O" or a blank. This suggests using an array, each location of which contains a character. We could use a 3 x 3 array:

```
DIM board$(3,3)
```

and select a square by using two numbers specifying a column and a row. However, we prefer to use a one-dimensional array:

```
DIM board$(9)
```

and we can then select a square by using a single number where the squares are numbered:

1	2	3
4	5	6
7	8	9

Thus at some stage in the game, we might have

O		X
	X	
O		

stored as

board$(1)	"O"
board$(2)	"."
board$(3)	"X"
board$(4)	"."
board$(5)	"X"
board$(6)	"."
board$(7)	"O"
board$(8)	"."
board$(9)	"."

where "." represents a blank square.
PROCstartgame is defined as:

```
100   DEF PROCstartgame
110   LOCAL square, reply$
120     DIM board$(9)
130     movesmade = 0
140     gameover = FALSE
150     blank$ = "."
160     FOR square = 1 TO 9
170       board$(square) = blank$
180     NEXT square

190     INPUT "Do you want to start, Y/N", reply$
200     IF reply$="Y" THEN
              computersturn = FALSE :
              opp$  = "X" : comp$ = "O"
        ELSE computersturn = TRUE  :
              comp$ = "X" : opp$  = "O"
210   ENDPROC
```

A variable 'movesmade' will be used for counting the moves so that we can easily recognise when the board is full.

A variable 'blank$' contains the character that is used to mark a blank square. Giving a name to this character will make it easier to change it to something else if we wish.

The player who makes the first move is "X" and the other player is "O". The variable 'comp$' contains the character ("X" or "O") being played by the computer and 'opp$' contains the character being played by the opponent.

We shall keep PROCdisplay as simple as possible. Each time that it is called, the characters in the noughts and crosses board will be printed on the screen:

```
300   DEF PROCdisplayboard
310   LOCAL square
320     PRINT : PRINT
330     FOR square = 1 TO 9
340       PRINT board$(square); " ";
350       IF square MOD 3 = 0 THEN PRINT
360     NEXT square
370     PRINT : PRINT
380   ENDPROC
```

The display produced by this procedure could be considerably improved but this is left as an exercise.

We must now define the two move making procedures. For the time being, the computer will select its moves completely at random. A random number in the range 1 to 9 is repeatedly generated until the number of a blank square is obtained. The character 'comp$' ("X" or "O") is then inserted in that square, the move is counted and 'computersturn' is set to FALSE. Note that when we want to improve the computers strategy we know that it is this procedure that we have to alter.

```
500   DEF PROCcomputer
510   LOCAL move
520     REPEAT
530       move = RND(9)
540     UNTIL board$(move) = blank$
550     PRINT "I play in square "; move
560     board$(move) = comp$
570     movesmade = movesmade + 1
580     computersturn = FALSE
590   ENDPROC
```

In PROCopponent, the move number made is obtained by using INPUT:

```
700   DEF PROCopponent
710   LOCAL move
720     INPUT "Your move, square number:" move
730     board$(move) = opp$
740     movesmade = movesmade + 1
750     computersturn = TRUE
760   ENDPROC
```

The procedure PROCtestgameover involves testing for rows of "X"s and rows of "O"s and it is convenient to define it in terms of other procedures:

```
900   DEF PROCtestgameover
910     PROCtestcomputerwin
920     IF computerwin THEN gameover = TRUE : ENDPROC
930     PROCtestopponentwin
940     IF opponentwin THEN gameover = TRUE : ENDPROC
950     IF movesmade = 9 THEN gameover = TRUE
960   ENDPROC
```

Of course we should not call both 'PROCtestcomputerwin' and 'PROCtestopponentwin'. The logical elaboration required to prevent both procedures being called is left as an exercise (below). PROCtestcomputerwin will search the board for a group of three of the computer's character in a straight line configuration. PROCtestopponentwin will search for a straight line configuration of the opponent's character. It is convenient to define these procedures in terms of a common function:

```
1000   DEF PROCtestcomputerwin
1010     IF FNrowof(comp$) THEN  computerwin = TRUE
                           ELSE  computerwin = FALSE
1020   ENDPROC


1100   DEF PROCtestopponentwin
1110     IF FNrowof(opp$) THEN   opponentwin = TRUE
                          ELSE   opponentwin = FALSE
1120   ENDPROC
```

FNrowof is a logical function that produces a result TRUE or FALSE. It is given a character as its parameter and tests all straight line combinations of three squares to see if there is such a combination of squares that all contain the given character. Each combination of three squares is tested by calling another function with three parameters indicating the numbers of the three squares to be tested:

```
1200   DEF FNrowof(letter$)
1210     IF FNthree(1,2,3) THEN  = TRUE
1220     IF FNthree(4,5,6) THEN  = TRUE
1230     IF FNthree(7,8,9) THEN  = TRUE
1240     IF FNthree(1,4,7) THEN  = TRUE
1250     IF FNthree(2,5,8) THEN  = TRUE
1260     IF FNthree(3,6,9) THEN  = TRUE
1270     IF FNthree(1,5,9) THEN  = TRUE
1280     IF FNthree(3,5,7) THEN  = TRUE
1290   =FALSE

1300   DEF FNthree(s1, s2, s3)
1310   =  (board$(s1) = letter$ AND board$(s2) = letter$
                                AND board$(s3) = letter$)
```

Note that the equals sign is being used for two different purposes on line 1310. The first one indicates that the value of the logical expression that follows (TRUE or FALSE) is the result of the function. The others are relational operators testing for equality.

There are many other ways in which the tests carried out by FNrowof could be arranged, by using various combinations of REPEAT loops. However, in view of the small number of combinations to be tested, the above approach is certainly the most straightforward.

The definition of PROCannouncewinner completes the program:

```
1400   DEF PROCannouncewinner
1410     IF computerwin THEN PRINT "I win!"
         ELSE IF opponentwin THEN PRINT "You win!"
              ELSE PRINT "It's a draw."
1420   ENDPROC
```

Several of the following exercises involve making improvements to the above program. You should notice when doing these exercises that the way in which the program was written makes it very easy to identify the part of the program text that needs to be changed to implement a particular improvement.

Exercises

1 The game 'last one loses' is played as follows:
Two players take turns at removing at least one and not more than three counters from a stack that initially contains 'n' counters where 'n' is chosen at random at the start of each game. The player who is forced to remove the last counter loses.
Write a program to play a game of 'last one loses'. Use

the same approach to writing this program as was used in writing the noughts and crosses program.

2 Extend the noughts and crosses program so that it starts by telling the opponent how to type moves. Use a procedure PROCinstructions.

3 As it stands, PROCopponent allows the computer's opponent to make illegal moves. Improve this procedure so that this possibility is dealt with.

4 If the computer has just made a move in the noughts and crosses program, it is a waste of time for PROCtestgameover to call PROCtestopponentwin. Similarly, if the opponent has just made a move, PROCtestcomputerwin should not be called. Reorganise PROCtestgameover so that unnecessary tests are eliminated.

5 The display produced by the noughts and crosses program could be improved in various ways. The code numbers of the various squares could be permanently displayed in the corner of the screen. The board itself could be permanently displayed in the centre of the screen and only the relevant square in the board changed (using TAB) when a move is made. Make these improvements.

6 Rewrite the noughts and crosses program so that it uses a two-dimensional array:

```
DIM board$(3,3)
```

to represent the board. Which version of the program do you prefer?

7 Try and improve PROCcomputer so that the program plays more 'intelligently'. The procedures PROCtestcomputerwin and PROCtestopponentwin might be useful here. For example, the program could try each possible move in turn and use PROCtestcomputerwin to see if it was a winning move.

Chapter 8 Special effects with characters and strings

In this chapter, we discuss various special effects that can be obtained with characters and strings on your Electron, but first, we present a little more information on how characters are stored and processed inside the machine.

8.1 How characters are stored

A character is stored inside the computer as an integer that occupies 8 bits or one byte. There is an internationally agreed standard set of codes for the commonly used characters. These are the ASCII codes (American Standard Code for Information Interchange). The first table in Appendix 7 contains a list of the normal display characters and their ASCII codes.

Conversion functions: ASC and CHR$
Two special functions are available for converting the first character of a string into its numeric code (ASC) and for converting a numeric code into a single character string (CHR$). The statement

```
PRINT ASC("+"), ASC("A"), ASC("a")
```

will print the numbers

```
          43        65        97
```

whereas the statement

```
PRINT CHR$(38); CHR$(75); CHR$(122)
```

will print the characters

```
&Kz
```

The following program inputs a sequence of 10 ASCII codes and builds up a string containing the 10 corresponding characters.

```
10   chars$ = ""
20   FOR i = 1 TO 10
30     INPUT "Next code ", code
40     chars$ = chars$ + CHR$(code)
50   NEXT i
60   PRINT "These codes make up "; chars$
```

The VDU statement

The VDU statement provides an alternative way of sending characters to the display hardware. The word VDU is followed by a list of character codes separated by commas and these codes are sent one by one to the screen. If the codes represent visible characters, then these characters will appear on the screen. Thus the two statements

```
VDU 65, 66, 67, 88, 89, 90
```

and

```
PRINT "ABCXYZ";
```

have exactly the same effect. However, the VDU statement is normally used for sending invisible characters or special control codes to the display hardware. For example, the ASCII codes from 1 to 31 are reserved for special purposes on the Electron and if one of these codes is sent to the display hardware, it is intercepted and handled specially.

For example, 8 is the code for 'backspace' and the statement

```
VDU 8, 8, 8
```

will move the cursor back 3 character positions on the current line. Note that the same effect can be obtained with

```
PRINT CHR$(8); CHR$(8); CHR$(8);
```

or with

```
back3$ = CHR$(8)+CHR$(8)+CHR$(8);
   .
   .
   .
PRINT back3$;
```

The string 'back3$' contains three invisible control characters that are sent to the display hardware when the string is printed.

In general there are many different ways of sending a sequence of characters (visible and control) to a device. The most appropriate depends on the application. The last

method above would be most convenient in a program that frequently required to send three backspaces. Once the string has been defined and given a name, the name can be included in a PRINT statement wherever it is required.

Various special control codes will be introduced and explained as they are required in this and later chapters. Tables of the various codes and a brief description of their effects appear in Appendix 7.

8.2 Coloured text and its uses

Control of the colour of characters is easily effected on the Electron from a BASIC program. The particular facilities discussed in this section are MODE, which selects a particular graphics and text mode for the screen, and COLOUR, which selects particular foreground and background colours for the characters. The modes available to you are numbered from 0 to 6. The computer normally operates in MODE 6 and you can always return to this mode by pressing BREAK or by typing MODE 6. For example you may be developing a program that runs in MODE 2. After an erroneous run, a listing in MODE 2 may not be particularly readable, and you could type MODE 6 (without a line number) and LIST the program in MODE 6. Alternatively you could add the following two lines at the bottom of every program:

```
300   keypress = GET
310   MODE 6
```

After a program in say MODE 2 has run pressing any key will clear the screen and return to MODE 6. You can also switch to MODE 6 by typing CONTROL-V followed by 6 or you might prefer to define one of the user-defined function keys to switch to MODE 6 and list the program. (See Appendix 1 to see how to do this.)

A summary of the character facilities and the colours normally available in each mode follows. You can see from this that, in general, as the number of characters available on the screen increases the colour options decrease. This is a point we will be examining in much more detail when we deal with graphics.

mode	colours available	characters per line	lines
0	2	80	32
1	4	40	32
2	16	20	32
3	2	80	25
4	2	40	32
5	4	20	32
6	2	40	25

Colour codes for 2-colour modes (0,3,4,6)

foreground	background	colour
0	128	black
1	129	white

Colour codes for 4-colour modes (1 and 5)

foreground	background	colour
0	128	black
1	129	red
2	130	yellow
3	131	white

Colour codes for 16-colour mode (MODE 2)

foreground	background	colour
0	128	black
1	129	red
2	130	green
3	131	yellow
4	132	blue
5	133	magenta
6	134	cyan
7	135	white
8	136	flashing black-white
9	137	flashing red-cyan
10	138	flashing green-magenta
11	139	flashing yellow-blue
12	140	flashing blue-yellow
13	141	flashing magenta-green
14	142	flashing cyan-red
15	143	flashing white-black

To select a particular mode we write, for example,

```
10  MODE 2
```

To select a particular foreground colour we write, for example,

```
20  COLOUR 1
```

To select a particular background colour we write, for example,

```
30  COLOUR 129
```

You can see from the tables that a background colour code is 128 plus the foreground colour code. Another way of putting it is to say that COLOUR refers to the foreground if the code stated is less than or equal to 15 and to the background if the code is greater than or equal to 128. The COLOUR statement changes the colour (foreground or background) used for subsequent printing (but not for drawing). The foreground and background colours of information already on the screen do not change. When a character is printed, the character itself is displayed in the current foreground colour against a small rectangle of the current background colour. If the background colour has not been changed, the background round the character is indistinguishable from the existing background colour on the screen. When the background colour is changed, characters are subsequently printed with a local background that is different from that round the characters previously printed. This behaviour is demonstrated below.

The following example uses local background colours. It prints two messages on the same line using a different combination of background and foreground colours for each message.

```
10   MODE 5
20   COLOUR 1
30   COLOUR 130
40   PRINT " red on yellow ";
50   COLOUR 2
60   COLOUR 129
70   PRINT " yellow on red "
```

Incidentally, note that if you type LIST after running this program the computer will continue to operate in the same mode using the most recently set up foreground and background colours. You should use one of the methods mentioned earlier to return to MODE 6.

If you want a background colour for the whole screen then CLS (clear screen) can be used. This, as the name implies, clears the screen entirely and sets the whole screen to the current background colour. Note the difference in effect between:

```
10   MODE 5
20   COLOUR 1
30   COLOUR 130
40   CLS
50   PRINT "red on yellow"
```

and:

```
10   MODE 5
20   COLOUR 1
30   COLOUR 130
40   PRINT "red on yellow"
```

Further examine the effect of:

```
10   MODE 5
20   COLOUR 1
30   COLOUR 130
40   CLS
50   PRINT "red on yellow"
60   COLOUR 2
70   COLOUR 129
80   PRINT "yellow on red on yellow"
```

The next program uses two isolated background colours as a simple method of plotting a bar graph or chart. It displays a bar chart representing the values in the DATA statement. These values must each be in the range 0 to 19. The bars of the chart are drawn horizontally.

```
 10   DATA 3,5,8,9,10,15,19,12,8,4
 20   MODE 5
 30   FOR i = 1 TO 5
 40     COLOUR 129
 50     READ h
 60     FOR j = 1 TO h
 70       PRINT" "; : NEXT j
 80     PRINT
 90     COLOUR 130
100     READ h
110     FOR j = 1 TO h
120       PRINT" "; : NEXT j
130     PRINT
140   NEXT i
```

In this program the local background colour alternates as red and yellow. We print spaces to make up the bars. A space consists entirely of background colour and the effect of printing a space without invoking CLS is to print a rectangle of the current background colour against a black whole screen background.

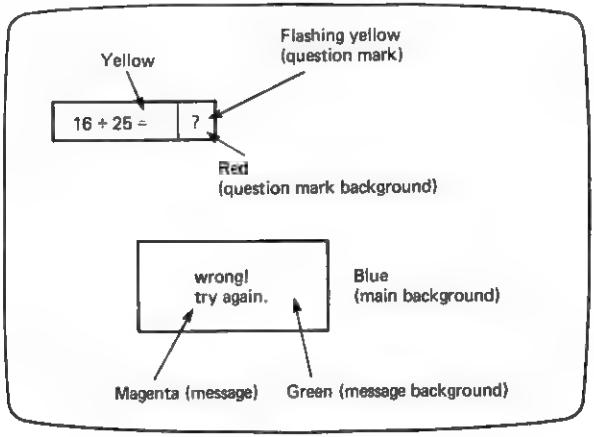
8.3 The use of flashing colour

Flashing colour available in MODE 2 can be used in computer dialogue to accentuate a particular part of a message or a piece of text. In the computer-assisted learning program of

Chapter 5, we were posing questions like:

```
16 + 25 = ?
```

Suppose we want to set up the screen as follows for this question:



This could be achieved by using the following procedures in MODE 2 (almost! see Exercise 1 below):

```
200  DEF PROCdisplayquestion
210    COLOUR 3
220    COLOUR 132
230    CLS
240    FOR i = 1 TO 4 : PRINT : NEXT i
250    PRINT "     "; a; " + "; b; " = ";
260  ENDPROC

300  DEF PROCgetanswer
310    COLOUR 11
320    COLOUR 129
330    INPUT answer
340  ENDPROC
```

```
400  DEF PROCwronganswer
410    FOR i = 1 TO 4 : PRINT : NEXT i
420    COLOUR 5
430    COLOUR 130
440    PRINT "             "
450    PRINT "   wrong!    "
460    PRINT " try again. "
470    PRINT "             "
480  ENDPROC
```

Note lines 310 and 320 that control the colour of the question mark. Also note that the question mark should not be printed from the program because it is supplied by the INPUT statement. You may find that you can obtain a better contrast between text and background by using different colours.

Exercises

1 The above procedures require further detailed development to give a blue area immediately to the left of the message display. Do this.

2 Once the display produced by the above procedures is satisfactory incorporate these facilities in a complete CAL program. Use the TAB function to move about the screen and be careful to switch colours and erase text (by overprinting with spaces) where appropriate. You may find that you need time delays to give the user time to read messages before they are erased.

3 Further develop the bar graph program so that the bars are two lines thick.

4 Write a bar graph program that produces a more conventional display with the bars running vertically. This is quite difficult - it can be done with TAB statements, but you may find it easier to build up the histogram in a two-dimensional array storing different codes for different coloured 'spaces'. The whole array can then be printed in the appropriate order, switching colours as required.

8.4 Changing the actual colour range of a mode

In this section we introduce a facility that allows the two or four colours available in MODE 0, 1, 3, 4, 5 or 6 to be any two or four of the 16 colours available in MODE 2. This means, for example, that flashing colours can be used in modes that do not normally provide flashing colour. It also means that 16 colours can be used in a program that uses MODE 1 or MODE 5 with the restriction that only four can

appear on the screen at any instant. The reason for using MODE 1 instead of MODE 2 might be that we need greater plotting accuracy or more readable characters for a particular application. We might use MODE 5 because we need more memory space. The memory requirements for MODE 0 to MODE 6 are 20K, 20K, 20K, 16K, 10K, 10K and 8K respectively. This memory is needed during program execution and reduces the memory available for program and data.

Recall that to specify a colour for subsequent display the COLOUR statement is used with a numeric parameter. The colour selected by this code number can be changed by the VDU 19 statement. This redefines or transforms the colour definitions. For example:

```
10   MODE 1
20   COLOUR 1
30   PRINT "colour 1 is red"
```

has the effect that you have already seen. The effect of

```
10   MODE 1
20   VDU 19, 1, 9, 0,0,0
30   COLOUR 1
40   PRINT "colour 1 is now flashing red"
```

is to change the definition of COLOUR 1 from its original red to flashing red (colour number 9 in the list for MODE 2). It is still called COLOUR 1 in the program.

The general form is:

VDU 19, | colour code number | , | actual colour number | , 0,0,0

This is a particular use of the VDU statement to send one of the control codes (19 in this case) mentioned in the first section of this chapter. Whenever the code 19 is sent, it must be followed by 5 other codes, the last three of which are usually 0. (If you miss out the zeros, the next three characters sent to the screen by PRINT or VDU statements are ignored.)

If we now refer back to the computer-assisted learning program, we can see that a similar effect in the question text can be achieved in MODE 1:

```
200  DEF PROCdisplayquestion
210    VDU 19, 3, 4, 0,0,0
220    COLOUR 2
230    COLOUR 131
240    CLS
250    FOR i = 1 TO 4 : PRINT : NEXT i
260    PRINT "    "; a; " + "; b; " = ";
270  ENDPROC

400  DEF PROCwronganswer
410    FOR i = 1 TO 4 : PRINT : NEXT i
420    VDU 19, 0, 5, 0,0,0
430    VDU 19, 1, 2, 0,0,0
440    COLOUR 0
450    COLOUR 129
460    PRINT "             "
470    PRINT "   wrong!    "
480    PRINT " try again. "
490    PRINT "             "
500  ENDPROC
```

The VDU 19 statements could, in fact, be obeyed only once at the start of the program. Remember in MODE 1 only 4 different colours can appear on the screen at once and for this reason we have omitted the colour change for the question mark and its background.

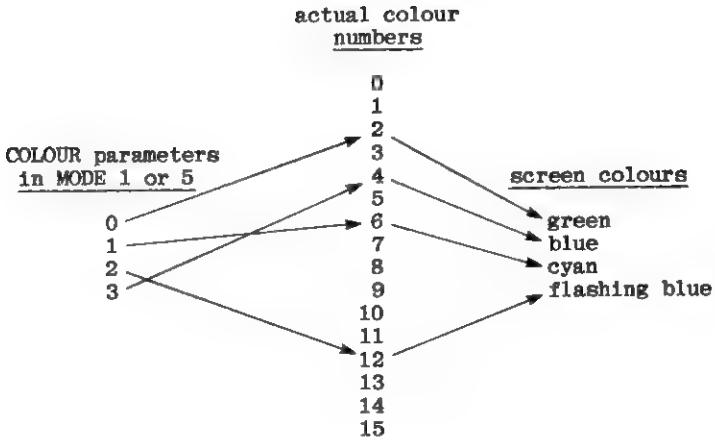
The complete set of 4 static colours could be changed to 4 flashing colours by using 4 VDU statements:

```
VDU 19, 0,  9, 0,0,0
VDU 19, 1, 10, 0,0,0
VDU 19, 2, 11, 0,0,0
VDU 19, 3, 12, 0,0,0
```

The process of colour redefinition is best imagined schematically as follows: suppose we want to make the colour codes 0, 1, 2, 3 refer to actual colours 2, 6, 12, 4 using the statements:

```
VDU 19, 0,  2, 0,0,0
VDU 19, 1,  6, 0,0,0
VDU 19, 2, 12, 0,0,0
VDU 19, 3,  4, 0,0,0
```

These statements set up 4 pathways to 4 of the possible actual colours. With the VDU statement we can set up any 4 pathways to 4 of the 16 possible actual colours.



When the VDU statement is used to change actual colours in this way, material already displayed on the screen is also affected. The following program illustrates this.

```
10   MODE 1
20   PRINT "Characters in COLOUR 3"

30   FOR actual = 1 TO 15
40     keypress = GET
50     VDU 19, 3, actual, 0, 0, 0
60   NEXT actual
```

If the above fragment is RUN, then each time a key is pressed the actual colour associated with code number 3 is changed and the colour of the message previously displayed with colour code 3 also changes. It is this feature that we exploit later in the chapter on animation.

8.5 String functions

String functions are standard functions that operate on a string and return either a number (for example the number of characters in a string) or another string (for example, part of the string being operated on).

String functions: numeric values (INSTR, LEN)
One of the most useful numeric string functions is INSTR. This searches for the occurrence of a substring within a string and returns a number that is the start position of the substring. For example:

```
10   string$ = "catatonic"
20   sub1$ = "cat"
30   sub2$ = "tonic"
40   PRINT INSTR(string$,sub1$), INSTR(string$,sub2$)
```

would print 1 followed by 5. This means that "cat" appears in "catatonic" starting at character position 1 and "tonic" appears starting at character position 5. If no match is found then zero is returned. Upper and lower case alphabetic characters are different in this context. If the total number of occurrences of a substring within a string is to be counted we could proceed:

```
10   quote$ = "curiouser and curiouser cried Alice"
20   INPUT "Word", word$
30   startlooking = 1 : noofocc = 0
40   REPEAT
50     position = INSTR(quote$, word$, startlooking)
60     IF position > 0 THEN noofocc = noofocc + 1:
          startlooking = position + LEN(word$)
70   UNTIL position = 0  OR  startlooking>LEN(quote$)
80   PRINT "Occurrences of "; word$; " are "; noofocc
```

In this program we have used an optional extra argument or parameter in INSTR. This causes the search to begin from the position in the string specified by this parameter. If a match is found the search must restart from a position at the end of the word just found. Otherwise there are no more occurrences of the string and the search can terminate immediately. Another feature introduced in this program is the function LEN. This returns an integer that is the length of the string, or the number of characters in it. The next illustration of INSTR could perhaps be the root of a medical diagnosis program tree. The aim of this fragment is to determine the tense of a reply to the question: "What is the matter with you?". The reply would be typed in by a patient or even input via a voice recognition system and the program is to be 'user friendly' (as they say), and interpret a wide range of possible replies.

```
10   INPUT reply$
20   IF    INSTR(reply$, "have been") <> 0
        OR INSTR(reply$, "have felt") <> 0
        OR INSTR(reply$, "had"      ) <> 0
        OR INSTR(reply$, "was"      ) <> 0
     THEN past = TRUE
     ELSE past = FALSE
30   IF past THEN PRINT"Are you feeling better now?"
     ELSE PRINT "What are your symptoms?"
```

It would, of course, have to be both more comprehensive and more flexible, but the fragment imparts a flavour of the dialogue processing that can be carried out using INSTR.

String functions: string values (LEFT$, RIGHT$, MID$)
The functions LEN and INSTR return numeric values. There are three string functions that return fragments or substrings of the string that they are operating on. These are LEFT$, RIGHT$ and MID$.

```
substring$ = LEFT$(string$, n)
```

sets 'substring$' to the first n characters of 'string$'

```
substring$ = RIGHT$(string$, n)
```

sets 'substring$' to the last n characters of 'string$'.

```
substring$ = MID$(string$, m, n)
```

sets 'substring$' to the fragment of 'string$' which contains n characters starting at character number m. The next program illustrates the use of MID$, and tests a sentence to see if it is a palindrome. For example, MADAM IM ADAM is a palindrome. If spaces are ignored it reads the same backwards. (The other palindromic sentences that make up this (in)famous dialogue are not fit for publication!)

```
 10   INPUT sentence$
 20   PROCtakeoutspaces
 30   FOR i = LEN(newsentence$) TO 1 STEP -1
 50     backwards$ = backwards$ + MID$(newsentence$, i, 1)
 60   NEXT i
 70   IF backwards$ = newsentence$ THEN
          PRINT "sentence is a palindrome"
      ELSE PRINT "sentence is not a palindrome"
 80   END

 90   DEF PROCtakeoutspaces
100     newsentence$ = ""
110     FOR i = 1 TO LEN(sentence$)
120       letter$ = MID$(sentence$, i, 1)
130       IF letter$ <> " " THEN
140             newsentence$ = newsentence$ + letter$
150    NEXT i
160   ENDPROC
```

The program also uses most of the string handling techniques introduced so far, such as comparing and appending strings. We have assumed that the palindrome is typed in upper case

letters throughout.

Note that the fragment extracted by MID$ is one character long. This is an extremely common use of MID$. Note also the procedure to extract spaces. Processing strings to manipulate spacing and change words forms the basis of word-processing programs. Right justification of text means that inter-word gaps have to be adjusted, such that the last character of a particular word in a line falls exactly on the end of the line. Changing every word for another involves searching (INSTR), for the word to be changed, making the necessary substitution, together with any length adjustment, that this substitution causes. The next program looks at this problem. It inputs a sentence, then a pair of words. The first word is the word to be replaced, the second the replacement word.

```
 10   INPUT sent$
 20   INPUT oldword$, newword$
 30   startlooking = 1
 40   REPEAT
 50     postn = INSTR(sent$, oldword$, startlooking)
 60     IF postn <> 0 THEN PROCinsertnewword:
                startlooking = startlooking + LEN(newword$)
 70   UNTIL postn = 0
 80   PRINT sent$
 90   END

100   DEF PROCinsertnewword
110     sent$ = LEFT$(sent$, postn - 1) + newword$
          + RIGHT$(sent$, LEN(sent$)-postn-LEN(oldword$)+1)
120   ENDPROC
```

String functions : conversion utilities (STR$, VAL)

Two associated functions for conversion between strings and numbers are STR$ and VAL. STR$ converts a numeric constant or the value of a numeric variable into a string constant. The following fragment sets up a string in 'date$', namely "19 January"

```
10   day = 19
20   month$ = "January"
30   date$ = STR$(day) + " " + month$
```

The function VAL does the opposite. It converts a numeric string into a numeric constant. The following would place the numeric constant 19 in numeric variable 'day'.

```
10   date$ = "19th. January"
20   day  = VAL(LEFT$(date$, 2))
```

The next program is a less trivial illustration of VAL. The program sorts three records containing a student name and mark into descending order of mark. We could handle the names and marks as separate entities, the names as strings and the marks as numeric variables, but this lengthens the program considerably and makes the programmer responsible for always remembering the link between the mark and the associated name. We can sort the strings as single entities by proceeding as we did elsewhere for sorting strings into alphabetic order except that this time we use the numeric part of the string to control the sort. 'record1$', 'record2$' and 'record3$' are each 14 characters long, say, with each mark contained in the last 4 characters.

```
10   INPUT record1$, record2$, record3$

20   IF VAL(RIGHT$(record1$,4)) < VAL(RIGHT$(record2$,4))
     THEN  temp$ = record1$:
           record1$ = record2$:
           record2$ = temp$

30   IF VAL(RIGHT$(record2$,4)) < VAL(RIGHT$(record3$,4))
     THEN  temp$ = record2$:
           record2$ = record3$:
           record3$ = temp$

40   IF VAL(RIGHT$(record1$,4)) < VAL(RIGHT$(record2$,4))
     THEN  temp$ = record1$:
           record1$ = record2$:
           record2$ = temp$
```

String functions : input (INKEY, INKEY$, GET, GET$)
These are functions that have been used liberally throughout the text so the treatment here need not be over long. The functions INKEY and INKEY$ wait a specified time (in hundredths of a second) to see if a key has been pressed. If a key has been pressed before the end of the time interval given, then INKEY returns the ASCII code of the key pressed and INKEY$ the character code of the key pressed. If a key has not been pressed by the end of the given time, INKEY returns -1 and INKEY$ an empty string. Thus

```
10   keypress = INKEY(200)
20   keypress$ = INKEY$(200)
30   PRINT  keypress, keypress$
```

This program prints one of

the code for A	if the A key is pressed once within two seconds
-1 followed by A	if the A key is pressed once, later than 2 seconds after RUN, but within 4 seconds
the code for A followed by A	if the A key is pressed once within 2 seconds and once again within the remainder of 4 seconds
-1	if no key pressed within 4 seconds

The following is another illustration of INKEY and could be the numeric control fragment of one 'reel' of a fruit machine program.

```
 5   CLS
10   number = 0
20   REPEAT
30     PROCdelay
40     number = (number + 1) MOD 10
50     PRINT TAB(20, 12); number
60     key$ = INKEY$(10)
70   UNTIL key$ = " "
80   END
```

The goal here might be to press the space bar and freeze a large number on the screen.

INKEY can also be used to test whether a particular key is pressed at the instant the function is called. This facility is controlled by using a negative parameter in INKEY. For details of how to do this, consult the User Guide.

The difference between the GET pair of functions, and the INKEY pair, is that the GET pair wait until a key is pressed, whereas the INKEY functions always give up after the specified time has elapsed, and continue executing the program. A common application of GET is in file listing. The computer prints a page from a file, then prompts the user with the question "more?". A "yes" answer causes printing to continue, a "no" answer stops the printing.

```
10   REPEAT
20     PROCprintapage
30     PRINT "more?"
40     keypress$ = GET$
50   UNTIL INSTR("Nn", keypress$)
```

Exercises

1 Write a program that counts the number of words containing four letters, in a sentence. You will find that the structure is simplified if words are separated by exactly one space and a sentence is terminated by a full stop preceded by a space.

2 Write a program that checks an entered line of text and prints a message indicating whether or not it satisfies the spelling rule: "i" before "e" except after "c".

3 Write a program that reports the longest word in a sentence.

Chapter 9 **Graphics**

In this chapter the exciting subject of computer graphics is explained in more detail. Although a sound basis of the foundation techniques in this fascinating subject is given, a complete coverage of computer graphics is beyond the scope of this text. The Electron incorporates many of the features found in more exotic and expensive processors and all the facilities available on the machine are explained at an introductory level.

The limitations of the Electron for advanced graphics are, of course, lack of processor power and secondly, a reduction in colour availability with increasing plotting accuracy. However the available facilities will support a wide variety of graphics applications. As well as dealing with straightforward plotting techniques we look at plotting involving logical operations (which gives the ability to divide images into separate planes), windowing, and basic interaction techniques from the keyboard. Some mathematics concerning shape generation is used in the chapter. You can ignore this with impunity if you are unhappy with it.

A logical presentation of the various PLOT, VDU and GCOL facilities means that these cannot be dealt with consecutively as they are presented in the User Guide. Rather they are introduced as required. Indeed some uses of the VDU statement have been introduced in a previous chapter and more are dispersed throughout this chapter.

9.1 Raster Scan displays

Although it is not strictly necessary to acquire an understanding of the functioning of the display hardware in your computer to write graphics programs, a rudimentary knowledge will make it easier to understand why display instructions are organised as they are. It will also make you appreciate the limitations of your machine and this will be especially useful when you come to do animation.

In a raster scan display a picture or image on the screen is organised as a collection of individual elements called 'pixels' or 'pels' in image-processing jargon. The number of pixels that the screen is divided into determines the accuracy or resolution to which we can draw pictures. Information about the colour of each pixel is stored in a 'refresh buffer' or 'screen memory'. The picture on the

screen is created by hardware that repeatedly scans this memory and colours the corresponding points on the screen. This scan takes place 50 times a second and any change made to the stored image causes an instantaneous change on the screen.

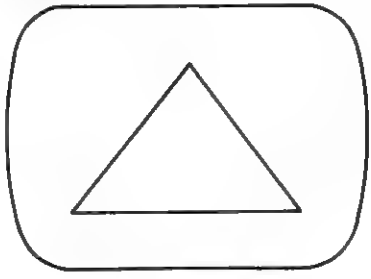
```
00000000000000000000000000
00000000000100000000000000
00000000001010000000000000
00000000010001000000000000
00000000100000100000000000
00000001000000010000000000
00000010000000001000000000
00000100000000000100000000
00001111111111111110000000
00000000000000000000000000
```

information stored in a raster scan memory for
a black/white or on/off triangle image

A raster scan display should not be confused with a random scan display, (a much more expensive device) in which a picture of, say, a triangle would be stored as three coordinate pairs. A raster scan beam can only move horizontally from left to right. It needs as many memory elements as there are pixels on the screen and there is a one-to-one correspondence between the screen memory and the pixel image. A line in a picture has to be drawn on the screen as a series of bright pixels that merge into one another. Whether or not this gives a satisfactory impression depends on the resolution. If, for example, we were operating in MODE 4 (320 pixels horizontally by 256 pixels vertically) then the memory can be imagined as a two-dimensional array of 320x256 elements.

```
          320
  00000000000000000000
  00000000010000000000
  00000000101000000000
  00000001000100000000
256 00000010000010000000
  00000100000001000000
  00001000000000100000
  00011111111111110000
  00000000000000000000
```

screen memory

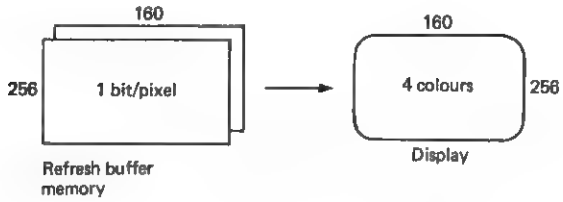


screen

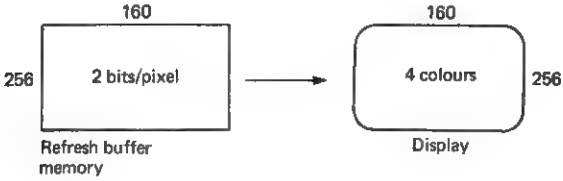
Each memory element in this mode can only store a 1 or 0 and

so the display is an on/off or two colour display. A row of memory elements in the screen memory corresponds to a horizontal band on the screen and the hardware continually scans through the memory, as the beam moves across the screen and provides an intensity modulated or on/off beam signal to drive the TV or monitor display. The screen memory is continually being scanned row by row, each row corresponding to a horizontal band on the display screen. The stream of bits that comes out of the memory has to be converted into a continuous or analogue signal that controls the beam intensity. The normal TV scanning and deflection electronics are used and synchronise or control the outflow of bits from the memory.

The memory requirement for MODE 4 is thus 320x256 bits (80K bits or 10K bytes). For an explanation of the terms bit and byte see Appendix 5. If we operate in MODE 5, the spatial resolution drops to 160x256. We can therefore imagine the memory to be organised as a two-dimensional array of 160x256 elements. This time, however, each pixel can be one out of 4 colours and this information needs 2 bits/pixel. (2 bits can be used to specify 4 states 00, 01, 10 and 11). Thus, although we have contracted the spatial resolution, the memory requirement is still 10K bytes (2x160x256 bits). MODE 5 memory organisation can be imagined as two planes of 1-bit memory cells.



or as a single plane of 2-bit memory cells.



Both concepts of the memory organisation - n planes of 1-bit cells, or 1 plane of n-bit cells - are important in graphics programming.

9.2 Screen coordinates

As already mentioned, the screen is organised into a two-dimensional array of pixels at a particular spatial resolution that depends on which mode is selected. We saw in Chapter 1 that, in a BASIC program, we specify points on the screen by using (x,y) coordinates. The question now is: what values of (x,y) correspond to a particular pixel? The answer to this may seem rather unusual but we shall explain the reason for it. The screen coordinate system used in a BASIC program is completely independent of mode and is a notional or imaginary system of 1280x1024, with (0,0) in the bottom L.H. corner. Thus to refer to a point in the top R.H. corner of the screen we would use (1279,1023). To refer to a point at the centre of the screen we would use (640,512). These coordinate addresses can be used in any of the graphics modes: 0,1,2,4 and 5. The display software then internally scales a point in the notional coordinate system into the mode system with a reduction in spatial resolution that depends on the mode selected. Thus the programmer always works in a 1280x1024 system and the display software rescales the program coordinates into the mode coordinates according to whatever mode is being used. The physical size of a pixel on the screen depends on mode number. In MODE 0 (640x256) the following program coordinates will refer to the same pixel - the one in the top R.H. corner

```
1278,1023       1279,1023
1278,1022       1279,1022
1278,1021       1279,1021
1278,1020       1279,1020
```

Thus executing the following will cause only one pixel to light up:

```
PLOT 69, 1278, 1023
PLOT 69, 1279, 1023
PLOT 69, 1278, 1022
PLOT 69, 1279, 1022
PLOT 69, 1278, 1021
PLOT 69, 1279, 1021
PLOT 69, 1278, 1020
PLOT 69, 1279, 1020
```

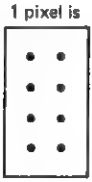
(PLOT is explained below and PLOT 69, x, y means plot a

single point at (x,y).) Conversely executing any one of these statements causes the same pixel to light up. You can see from this that in MODE 0 there are 8 pairs of program coordinates referring to 1 screen pixel. Similarly in MODE 1 (320x256) there are 16 pairs of program coordinates for each screen pixel. To refer to a screen pixel only one pair of program coordinates for that pixel needs to be used.

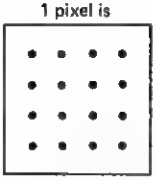
The reason for doing things this way is that a program can be run at different resolutions by simply changing the MODE statements. A program that runs in MODE 1 will run in MODE 0 at a higher resolution because the same notional coordinate system has been used in both cases. The shape of graphics images will be preserved (subject of course to the limitation that changing resolution does in itself result in a shape change).

The pixel geometry with respect to the MODE resolution is as follows:

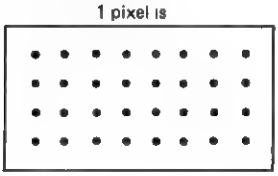
MODE 0 : 640 x 256
8 points/pixel



MODE 1 : 320 x 256
16 points/pixel
(also MODE 4)



MODE 2 : 160 x 256
32 points/pixel
(also MODE 5)



To demonstrate the changing pixel geometry try running the following:

```
10   FOR mode = 0 TO 2
20     MODE mode
30     PLOT 69, 640, 512
40     keypress = GET
50   NEXT mode
```

Pixel separation

Another experiment that you should try demonstrates the ability or inability of your display monitor to separate pixels at the required resolution. The most 'complex' or 'busiest' pattern that we can plot is a checkerboard pattern of alternating bright and dark, where each checkerboard element is 1 pixel. To generate one line of such a pattern in MODE 4 we would proceed as follows:

```
10   MODE 4
20   scale = 4
30   FOR x = 0 TO 1279 STEP scale*2
40     PLOT 69, x, 512
50   NEXT x
```

PLOT 69 plots a bright point. We step 'scale*2' each time because we are brightening up every second pixel. Now if you are using a domestic TV you will find that it is difficult if not impossible to see the blank pixels between the bright or on pixels. You will get a greyish continuous line with a hint of the on/off alternation. Adding

```
60   MOVE 0, 500
70   DRAW 1279, 500
```

will demonstrate the difference between this pattern and a continuous line. Now the resolution of this pattern can only be improved by using a monitor. This effect must therefore be borne in mind if you intend using individual pixels as significant dots to make up patterns.

The next fragment does the same thing in MODE 5 in alternating colours black, red, yellow, blue, black, etc. This time you can see that there is a colour resolution limitation - the colours tend to spill into each other.

```
10   MODE 5
20   scale = 8
30   VDU 19, 3, 4, 0,0,0
40   colour = 0
50   FOR x = 0 TO 1279 STEP scale
60     GCOL 0, colour
70     PLOT 69, x, 512
80     colour = (colour + 1) MOD 4
90   NEXT x
```

The use of GCOL 0 was explained in Chapter 1. Line 80 resets 'colour' to 0 when its value reaches 4.

9.3 The PLOT statement : introduction

The PLOT statement is a multi-purpose line and point plotting procedure.

```
PLOT k, x, y
```

plots to a new point specified by x and y. The type of plotting that takes place is determined by the value of k. The simplest uses of PLOT involve values of k from 0 to 7:

k = 0 Move relative to the last point. "Move" means don't plot a visible line.

k = 1 Draw a line relative to the last point in current graphics foreground colour.

k = 2 As 1 but in logical inverse colour (this is not necessarily the background colour - see Appendix 5).

k = 3 As 1 but in current background colour.

Options 0 to 3 are relative plotting commands. This means that the x and y quoted in 'PLOT k, x, y' are not absolute coordinates (in the 1280x1024 notional system) but relative coordinates. They specify the distance of the new point from the current point. Values of k from 4 to 7 have the same effect as 0 to 3 but absolute coordinates are quoted.

Higher values of k have other effects. The higher values are made up of a base value that selects a plotting effect plus one of the values 0 to 7 that modify that effect as we have already described. For example the base value 64 means plot a single point. We saw above that k = 5 means plot to a point whose absolute coordinates are given. Thus k = 64 + 5 = 69 means PLOT a single point at a specified absolute position. This is the PLOT 69 facility that has been informally introduced already. Similarly k = 64 + 1 means plot a single point at a position specified relative to the

current position. In other words the series of PLOTs based on the value 64 differ in effect from those based on 0 by only plotting the last point on the line connecting the current and previous points. The most useful base values are

```
 0    for plotting lines
16    for plotting dotted lines
64    for plotting single points
80    for filling a triangular area with colour (see later)
```

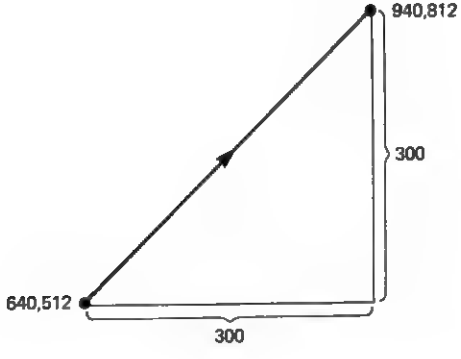
The value of having a relative plot facility will become obvious as the chapter progresses. If we were drawing a single line from say (640,512) to (940,812) we could either use

```
PLOT 4, 640, 512
PLOT 5, 940, 812
```

which uses absolute coordinates to establish both the start and the finish of the line; or we could use

```
PLOT 4, 640, 512
PLOT 1, 300, 300
```

which uses absolute coordinates to establish the start of the line and relative coordinates to draw to the end of the line.



We have already seen that because PLOT 4 and PLOT 5 are likely to be the most commonly used PLOT facilities, these can be written as:

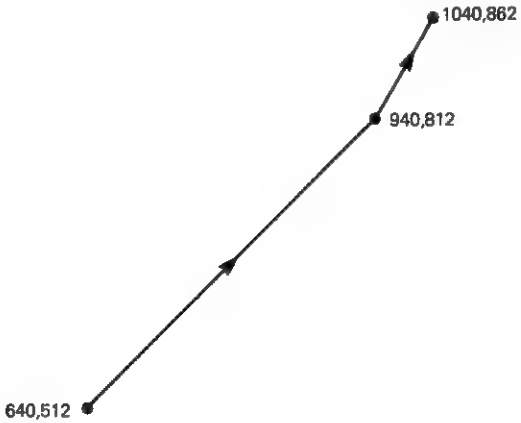
```
MOVE x, y        (PLOT 4, x, y)
DRAW x, y        (PLOT 5, x, y)
```

Thus all of the following have exactly the same effect:

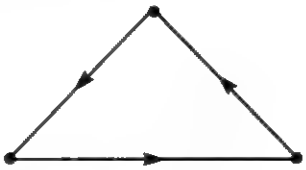
```
PLOT 4, 640, 512          MOVE 640, 512
PLOT 5, 940, 812          DRAW 940, 812

PLOT 4, 640, 512          MOVE 640, 512
PLOT 1, 300, 300          PLOT 1, 300,300
```

All graphics systems, whether electronic or electromechanical, operate from the 'current position' or CP. The CP is the point arrived at after the execution of a graphics plot statement. For example:

```
MOVE 640, 512      :    CP is now (640,512)
PLOT 1, 300, 300   :    CP is now (940,812)
DRAW 1040, 862     :    CP is now (1040,862)
```



Now relative coordinates are extremely useful when building up a picture using modules or sub-pictures. Suppose we wanted to draw a triangle at any absolute position on the screen in the following manner:



Absolute start position

We could define a procedure as follows:

```
100    DEF PROCdrawatriangleat(absx, absy)
120     MOVE absx, absy
130     PLOT 1, 60, 0
140     PLOT 1, -30, 30
150     PLOT 1, -30, -30
160    ENDPROC
```

and this procedure could be called with any absolute coordinates:

```
PROCdrawatriangleat(640, 512)
```

We could draw 10 triangles on an imaginary diagonal line with the following:

```
 5   MODE 4
10   absx = 0 : absy = 0
20   FOR i = 1 TO 10
30     PROCdrawatriangleat(absx, absy)
40     absx = absx + 30 : absy = absy + 30
50   NEXT i
60   END
```

We could draw triangles that get bigger and bigger by redefining the procedure as:

```
100   DEF PROCdrawatriangleat(absx, absy, size)
110     MOVE absx, absy
120     PLOT 1, 60 * size, 0
130     PLOT 1, -30 * size, 30 * size
140     PLOT 1, -30 * size,-30 * size
150   ENDPROC
```

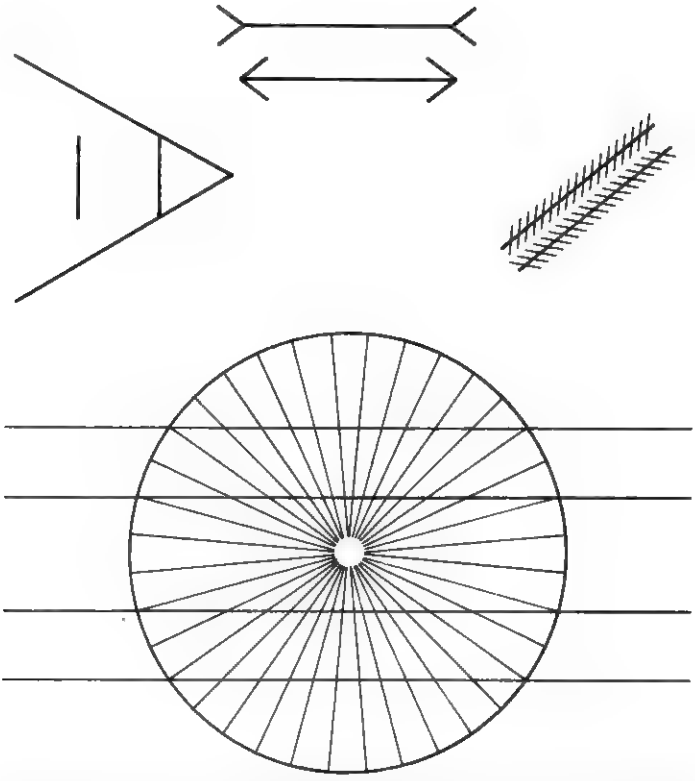
and calling the procedure with:

```
30   PROCdrawatriangleat(absx, absy, i)
```

where 'i' is the program loop control variable used in the above program. It now controls the size of each triangle. You can perhaps begin to see from these examples the usefulness of having a relative plotting facility. Using procedures to define subpictures is a topic explored in more detail below.

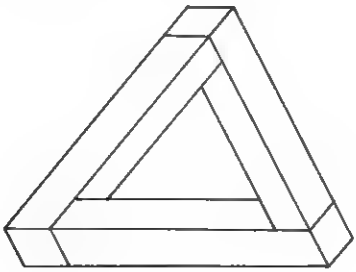
Exercises

1 Write a program to display a selection of the classical optical illusions:



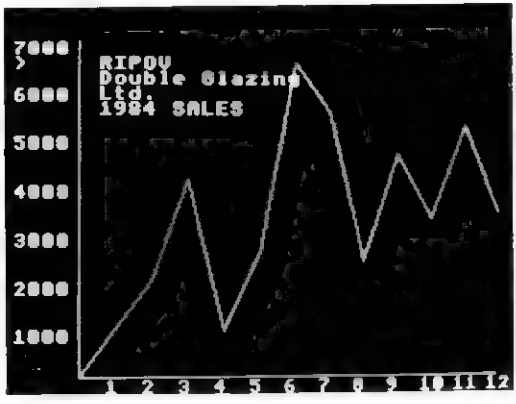
The first two are straightforward, the second two should be structured using a procedure and loop. Circle generation was introduced in Chapter 4 (or see later in this chapter).

2 Write a program to draw the impossible triangle. (Note that you can structure your program by using the fact that 6 of the figures are parallelograms and 3 are quadrilaterals.)



PLOT : simple graphs and origin translation

Drawing graphs is one of the most obvious and common applications of line-drawing statements in computer graphics. We may have a set of 365 daily temperature readings or 12 monthly sales figures and wish to display this data graphically in the familiar way with the variations in the data plotted in the y direction:



The following produces a first approximation to this:

```
  10   MODE 4
  20   xscale = 80 : yscale = 1/10
  30   DRAW 0, 7000*yscale
  40   MOVE 0, 0
  50   DRAW 12*xscale, 0
  60   MOVE 0, 0

  70   FOR month = 1 TO 12
  80     READ monthlysales
  90     DRAW month * xscale, monthlysales * yscale
 100   NEXT month

1000   DATA 1023, 2056, 4132, ...
```

The origin is at the default position of (0,0) and lines 20 to 50 draw the vertical and horizontal axes. Note that after drawing the vertical axis we return to the origin (MOVE 0,0) to draw the horizontal axis. Each monthly sales figure is read from a DATA statement or perhaps in practice from a file. Lines are drawn from one monthly sales figure to the other giving a standard piecewise linear graph. The graph could be started from the correct height for month 1 with

the added complication of:

```
draw the axes

READ monthlysales
MOVE xscale, monthlysales*yscale

FOR month = 2 TO 12

  rest as before
```

The other point to note is the scaling. The vertical extent of the graph must be decided on and the data scaled accordingly. The horizontal extent depends on the desired size and number of data points. In the above program we have used two extra variables to emphasise this point.

The next improvement to be made to the graph is to shift the origin diagonally in towards the centre to make way for legendry along each axis. We can do this by leaving the program exactly as it is and establishing a new graphics origin (0,0) anywhere on the screen by using VDU 29. Suppose we want the new origin to be (256,256). We need

```
15   VDU 29, 256; 256; : MOVE 0,0
```

and this single line added to the above program will plot the same graph in a position nearer the centre of the screen. Incidentally, note the use of semicolons in the VDU statement. A semicolon succeeding a parameter means that the parameter is to be interpreted as a double byte. Two bytes are needed to specify any coordinate in the notional 1280x1024 system.

Graphics legendry

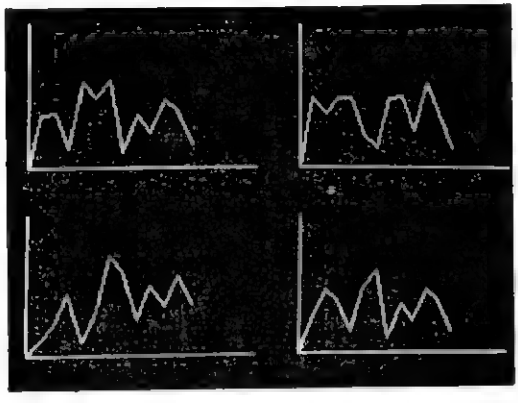
Having created the necessary space for the legendry by translating the origin we can now proceed to add the legendry by continuing the program as follows:

```
110   VDU 5
120   FOR month = 1 TO 12
130     MOVE month*xscale-24, -10
140     PRINT ;month
150   NEXT month

160   FOR sales = 1000 TO 7000 STEP 1000
170     MOVE -150, sales*yscale
180     PRINT ;sales
190   NEXT sales
```

The VDU 5 statement makes any subsequent text printed appear at the graphics CP. The text PRINTs can thus be controlled in the standard way by a FOR statement. Each PRINT is preceded by a MOVE to establish the text position. Note the use of the semicolon in the PRINT statements; this is to override the normal right-justified formatting and ensure that the integers are printed left-justified from the CP. Finally note the negative coordinates in the MOVE command. Remember that the (0,0) origin is now no longer physically at (0,0) on the screen and the negative displacements prevent the text from coinciding with the axes.

Multiple graphs

Another common use of origin translation is the production of a number of graphs on the same screen using the same program module to generate each:



We may want to display, for example, four annual sales characteristics on the same display. In the following program we use exactly the same process as before, now incorporated in a procedure, and call the procedure four times. Each time the procedure is called, its parameters define a new origin.

```
10   MODE 4
20   xscale = 30 : yscale = 1/30
30   PROCdrawgraph(0, 0)
40   PROCdrawgraph(0, 500)
50   PROCdrawgraph(600, 0)
60   PROCdrawgraph(600,500)
70   END
```

```
 80   DEF PROCdrawgraph(ox, oy)
 90     VDU 29, ox; oy;
100     MOVE 0, 0
110     DRAW 0, 400
120     MOVE 0, 0
130     DRAW 500, 0
140     MOVE 0, 0
150     FOR month = 1 TO 12
160       READ monthlysales
170       DRAW month*xscale, monthlysales*yscale
180     NEXT month
190   ENDPROC

200   DATA ... 48 monthly sale figures ...
```

Shape generation and basic mathematical plotting

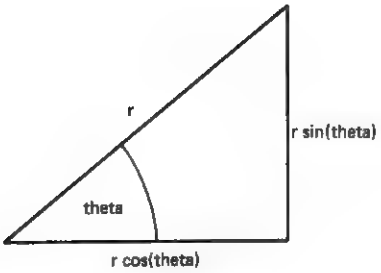
We shall start this section by illustrating some points concerning the generation of probably the most common mathematically generated shape - the circle. The following generates a 'circle' by plotting a regular polygon of 36 sides. The basic idea was introduced in Chapter 4; here we have simply incorporated the process in a procedure, making the centre and radius parameters.

```
 10   MODE 4
 20   INPUT xc, yc, r
 30   PROCdrawcircle(xc, yc, r)
 40   END

 50   DEF PROCdrawcircle(xc, yc, r)
 60     MOVE xc + r, yc
 70     FOR theta = 10 TO 360 STEP 10
 80       x = r*COS(RAD(theta))
 90       y = r*SIN(RAD(theta))
100       DRAW xc + x, yc + y
110     NEXT theta
120   ENDPROC
```

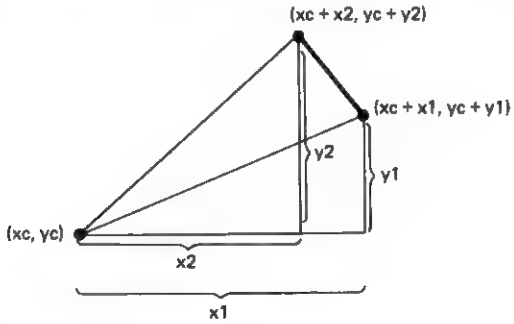
In this process we are using what mathematicians call polar coordinates. We are working mathematically in polar coordinates - a point is represented by the two values r and theta, and we convert r and theta into Cartesian coordinates x and y using:

x = r cos(theta)

y = r sin(theta)



Increments in 'theta' result in new (x,y) coordinates, one (x,y) pair for each vertex on the polygon.



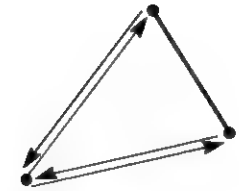
We can make the polygon approach a better and better circle by reducing the FOR loop increments in "theta". Now if we replace line 100 with:

```
100   PLOT 69, xc + x, yc + y
```

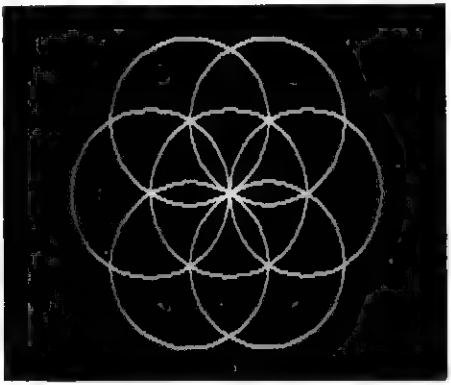
then we get a circle comprising 10 dots, one at each vertex, instead of 10 lines. If we add:

```
100   MOVE xc, yc
105   PLOT 69, xc + x, yc + y
```

this has no apparent effect, but instead of moving from vertex to vertex on the polygon we are now moving from the centre along a radius to a vertex each time. We are generating the circle by sweeping the radius rather than than following the circumference. This difference is important in colour fill (later).

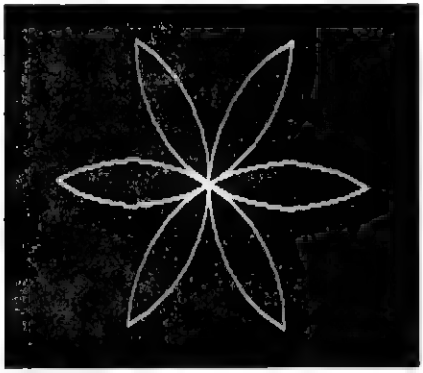


The next two programs will help develop your understanding of polar coordinates. The first program generates a circle then 6 circles of the same radius centred at 60 degree intervals on the circumference of the first:



```
 10   MODE 4
 20   INPUT sx, sy, r
 30   PROCdrawcircle(sx, sy, r)
 40   FOR circle = 0 TO 320 STEP 60
 50     xc = sx + r*COS(RAD(circle))
 60     yc = sy + r*SIN(RAD(circle))
 70     PROCdrawcircle(xc, yc, r)
 80   NEXT circle
 90   END

100   DEF PROCdrawcircle(xc, yc, r)
110     MOVE xc + r, yc
120     FOR theta = 10 TO 360 STEP 10
130       x = r*COS(RAD(theta))
140       y = r*SIN(RAD(theta))
150       DRAW xc + x, yc + y
160     NEXT theta
170   ENDPROC
```

Now if we take the above program and constrain the radial sweep of each of the 6 subsidiary circles so that they only appear when they are contained by the first circle (which is no longer drawn), we get the familiar 'petal' diagram:



```
 10   MODE 4
 20   INPUT sx, sy, r
 30   t1 = 120 : t2 = 240
 40   FOR circle = 0 TO 320 STEP 60
 50     xc = sx + r*COS(RAD(circle))
 60     yc = sy + r*SIN(RAD(circle))
 70     PROCdrawcircle(xc, yc, r)
 80     t1 = t1 + 60 : t2 = t2 + 60
 90   NEXT circle
100   END

110   DEF PROCdrawcircle(xc, yc, r)
120     x = r*COS(RAD(t1)) : y = r*SIN(RAD(t1))
130     MOVE xc + x, yc + y
140     FOR theta = t1+10 TO t2 STEP 10
150       x = r*COS(RAD(theta))
160       y = r*SIN(RAD(theta))
170       DRAW xc + x, yc + y
180     NEXT theta
190   ENDPROC
```

We leave you the reader to work out the geometry! 't1' and 't2' constrain the circumferences of each of the subsidiary circles, and have to be advanced by 60 degrees each time. We shall be returning to this diagram later to show how to colour fill it.

A more 'complex' shape than a circle is an ellipse. Without worrying about the maths too much the equation for an ellipse is:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} = 1$$

where a and b are the semi-major and semi-minor axes. In polar coordinates this gives:

```
r = 1/SQR(cos(theta)*cos(theta)/(a*a) +
                    sin(theta)*sin(theta)/(b*b))
```

The program is just that for the circle with the polar coordinate equation changed and some concession to numerical efficiency made:

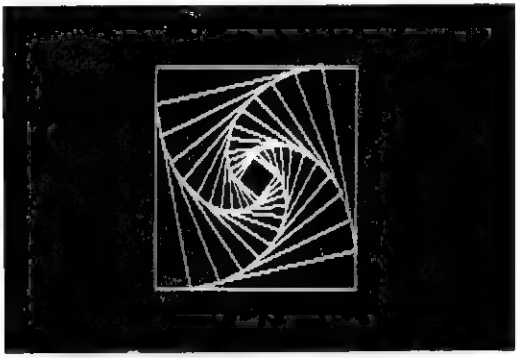
```
 10  MODE 4
 20  INPUT xc, yc, a, b
 30  MOVE xc + a, yc
 40  FOR theta = 10 TO 360 STEP 10
 50    cosine = COS(RAD(theta))
 60    sine   = SIN(RAD(theta))
 70    r = 1/SQR(cosine*cosine/(a*a)+sine*sine/(b*b))
 80    x = r * cosine : y = r * sine
 90    DRAW xc + x, yc + y
100  NEXT theta
```

Another common application of mathematical computer graphics is plotting a function of a single variable defined by an equation. This procedure is identical both conceptually and practically to drawing simple graphs of sales data or temperature readings. The only difference this time is that the y data are values given by a mathematical equation. The next program plots that old chestnut - the sine wave:

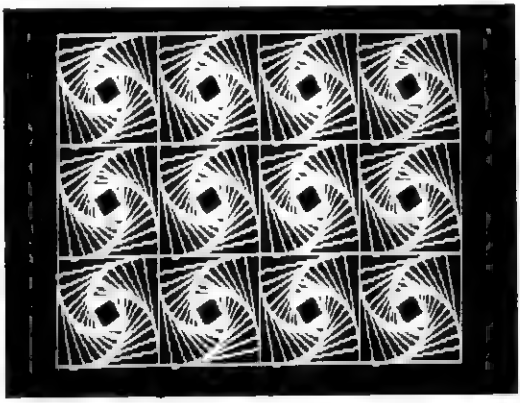
```
 10  MODE 4
 20  VDU 29, 100; 500;
 30  MOVE 0,0
 40  DRAW 1000, 0
 50  MOVE 0, -300
 60  DRAW 0, 300
 70  yscale = 300
 80  MOVE 0,0
 90  FOR x = 0 TO 1000
100    y = SIN(RAD(x))
110    DRAW x, y*yscale
120  NEXT x
```

Exercises

1 Write a procedure to draw a square. Call this procedure from within a loop that decreases the size of the square and increases its rotation or orientation. You will find that this produces a pattern that appears to consist of interacting spirals, providing that you plot a sufficiently large number of squares.



2 Using a nested FOR loop that sets up a grid of origins, fill the screen with a set of such patterns of rotating squares.



3 Lissajous figures are produced by interacting sine waves controlling coordinate values. For example:

```
x = r * COS(RAD(theta))
y = r * SIN(RAD(theta))
```

produces a circle as we've already seen. Experiment with:

```
x = r * COS(RAD(theta * order))
y = r * SIN(RAD(theta))
```

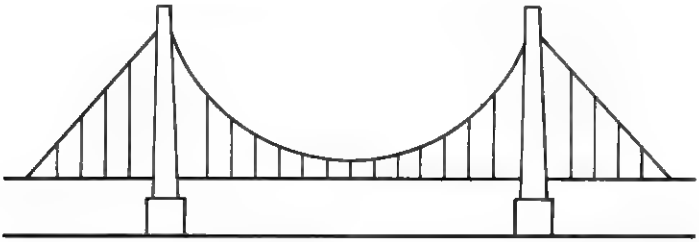
the interaction of a sine wave with another at 2 times, 3 times, 4 times the frequency.

4 The Lissajous figure plotted using

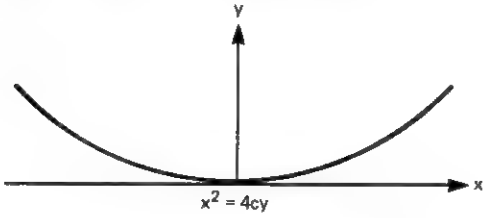
```
x = a * COS(RAD(theta))
y = b * SIN(RAD(theta))
```

gives a more efficient way of drawing an ellipse than the method using polar coordinates. Write a program to plot an ellipse in this way.

5 Write a program to plot a simple diagram or stylisation of a suspension bridge:



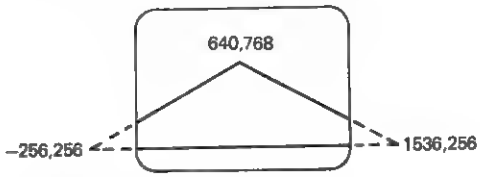
The span between piers is to be an input variable and the pier height proportional to span. The chain curve is a loaded catenary that can be approximated by a parabola:



PLOT : windows

As the name implies a window is a definable rectangular area on the screen within which the effect of any (visible) graphics statement is made visible. Graphic statements that have effect outside the window are invisible. The window, if

unspecified, is the screen area (1280x1024). The point of having a window equal to the screen area may not be at all obvious to you if you are new to computer graphics; but it is a vital facility. It means that you can specify coordinates outside the screen area with impunity, and have that part of the resulting image that lies on the screen preserved without distortion. For example specifying a triangle with 2 vertices off the screen would result in:



If there were no windowing facility the shape of the visible portion of the figure would be unpredictable and would depend on the magnitude of the off screen coordinates. The use of this facility together with using a window smaller than the screen area is really a topic in advanced computer graphics. It is used in selecting sub-areas of a graphics display for 'magnification' for example and can be used in generating mathematical figures that would be difficult to generate without this facility. We finish off this section with a demonstration of the latter. The next program fills the screen with a spiral. Note that the default screen window comes into effect, the line moving off the screen and back on again.

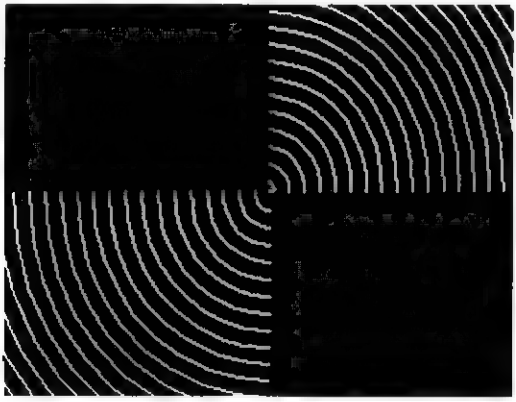
```
 10   MODE 4
 20   PROCdrawspiral
 30   END

 40   DEF PROCdrawspiral
 50     r = 10
 60     MOVE 640, 512
 70     FOR theta = 0 TO 7200 STEP 10
 80       r = r + 1
 90       x = r* COS(RAD(theta))
100       y = r* SIN(RAD(theta))
110       DRAW 640 + x, 512 + y
120     NEXT theta
130   ENDPROC
```

We can specify the size and the position of a window by using the VDU 24 statement. For example:

```
VDU 24, x1; y1; x2; y2;
```

specifies a window between x = x1 and x = x2; and y = y1 and y = y2. We give the x-y coordinates of the bottom left-hand corner of the window followed by the x-y coordinates of the top right-hand corner of the window. Note the semicolons which are essential. If we now insert two window commands and draw the spiral after each we generate the same pattern as before with two quadrants blanked out:

```
15    VDU 24, 0; 0; 640; 512;
20    PROCdrawspiral
25    VDU 24, 640; 512; 1279; 1023;
30    PROCdrawspiral
35    END
```



Note that we have to draw the spiral twice - we cannot have two windows active at once. If, for example, we omitted line 20 above, plotting would take place only in the most recently defined window - the top right quadrant. Line 15 would have no effect whatever. Now each time the spiral is plotted processing still takes place 'in the dark regions'. As far as the computer is concerned we are drawing the complete spiral twice.

Colour fill

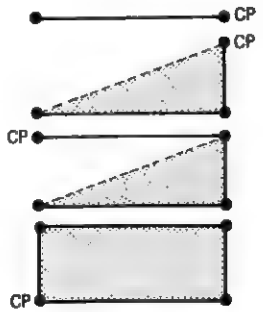
Filling the interior of a closed figure with a colour can be accomplished by using the triangular fill facility which is yet another PLOT option. Not all closed figures can be filled using this facility and general algorithms exist to fill closed figures irrespective of their shape. However, these will take a much longer time to execute than the triangular fill facility and much can be accomplished using this method as we shall now describe.

The PLOT facilities 0 to 7 are available with triangular fill as 80 to 87 where, for example,

```
PLOT 85, x, y
```

would draw a line from the CP to (x,y) absolute and would fill, in the current foreground colour, the triangular area defined by (x,y) and the last two points visited or the last two positions of the CP. For example to draw and fill a rectangle we could use the following:

```
10   PLOT 1, 100, 0

20   PLOT 81, 0, 50

30   PLOT 1, -100, 0

40   PLOT 81, 0, -50
```



Remember that the CP starts at (0,0). We could accomplish the same effect with:

```
10   PLOT  1, 100, 0
20   PLOT 81, 0, 50
30   PLOT 81, -100, 0
40   PLOT 81, 0, -50
```

but the computer would take slightly longer to do it - part of the area is being filled twice over. We now return to our circle generating module, the one that used a radial sweep. By changing

```
MOVE xc, yc
PLOT 69, xc + x, yc + y
```

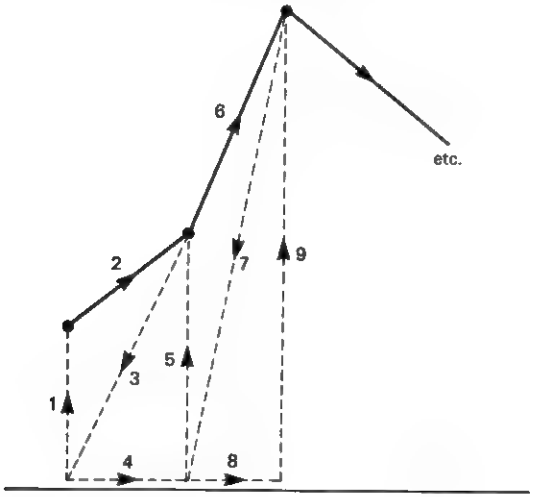
to

```
MOVE xc, yc
PLOT 85, xc + x, yc + y
```

we will generate a filled circle:

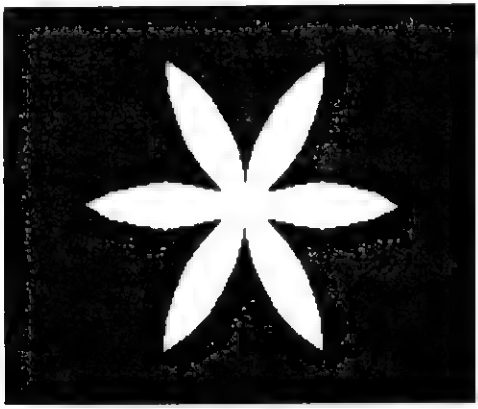
```
10   MODE 4
20   INPUT xc, yc, r
30   MOVE xc + r, yc
40   FOR theta = 10 TO 360 STEP 10
50     x = r*COS(RAD(theta))
60     y = r*SIN(RAD(theta))
70     MOVE xc, yc
80     PLOT 85, xc + x, yc + y
90   NEXT theta
```

Similarly our sales graph could be filled by returning to the x axis after each point is plotted. The program is just a generalisation of the rectangular plot and fill.




```
10   MODE 4
20   xscale = 80 : yscale = 1/10
30   MOVE xscale, 0
40   READ monthlysales
50   DRAW xscale, monthlysales*yscale : REM STEP 1
60   FOR month = 2 TO 12
70     READ monthlysales
80     x = month*xscale : y = monthlysales*yscale
90     DRAW x,y                          : REM STEP 2
100    PLOT 81, -xscale, -y              : REM STEP 3
110    PLOT 0, xscale, 0                 : REM STEP 4
120    PLOT 81, 0, y                     : REM STEP 5
130  NEXT month
140  DATA ...
```

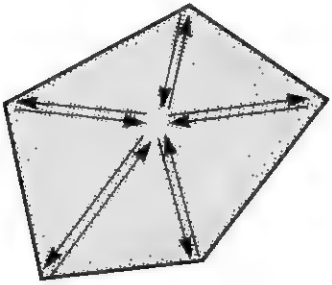
The next program generates and fills the 'petal' diagram. It is a useful exercise to follow through the triangular fill sequence as we did with the sales graph fill. The program demonstrates that even quite complicated mathematically generated figures can be filled using the basic triangular fill.



```
 10  MODE 4
 20  t1 = 120 : t2 = 240
 30  INPUT sx, sy, r
 40  FOR circle = 0 TO 320 STEP 60
 50    xc = sx + r*COS(RAD(circle))
 60    yc = sy + r*SIN(RAD(circle))
 70    PROCdrawcircle(xc, yc, r)
 80    t1 = t1 + 60 : t2 = t2 + 60
 90  NEXT circle
100  END

110  DEF PROCdrawcircle(xc, yc, r)
120    x = r*COS(RAD(t1)) : y = r*SIN(RAD(t1))
130    MOVE xc + x, yc + y
140    FOR theta = t1 + 10 TO t2 STEP 10
150      x = r*COS(RAD(theta))
160      y = r*SIN(RAD(theta))
170      x = xc + x : y = yc + y
180      MOVE sx, sy
190      PLOT 85, x, y
200    NEXT theta
210  ENDPROC
```

You can perhaps see from all this that we can generalise and say that any regular or irregular polygon can be filled using triangular fill by the simple expedient of moving to any point within the interior before plotting to each

vertex. Also we must start from a vertex.



Thus a contour map plotted from a DATA statement could be easily filled. There is a snag! Choosing any interior point will work only if the polygon is convex; this means that if it is a contour map of an island it must not contain any estuaries or else part of the sea may get filled. For some non-convex shapes, a suitable interior point can be found with some care, but for others no single interior point will do. The methods for overcoming this snag are a little tedious. Thus to plot a contour map or convex irregular polygon unfilled:

```
10   MODE 4
20   READ noofvertices
30   READ xs, ys
40   MOVE xs, ys
50   FOR i = 2 TO noofvertices
60     READ x, y
70     DRAW x, y
80   NEXT i
90   DRAW xs, ys
```

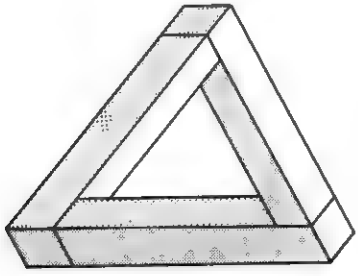
To plot a polygon filled:

```
 .... find an interior point (xi,yi) ....
100   READ xs, ys
110   MOVE xs, ys
120   FOR i = 2 TO noofvertices
130     READ x, y
140     MOVE xi, yi
150     PLOT 85, x, y
160   NEXT i
170   MOVE xi,yi : PLOT 85, xs, ys
```

where (xi,yi) is an interior point. Working out an interior point of course requires an a priori scan of the data. The centre of the minimum enclosing rectangle for example would suffice. To fill in contours within contours in different colours you can adopt the same approach and include GCOL facilities introduced below.

Exercises

1 Repeat the impossible triangle program but this time colour fill the faces.



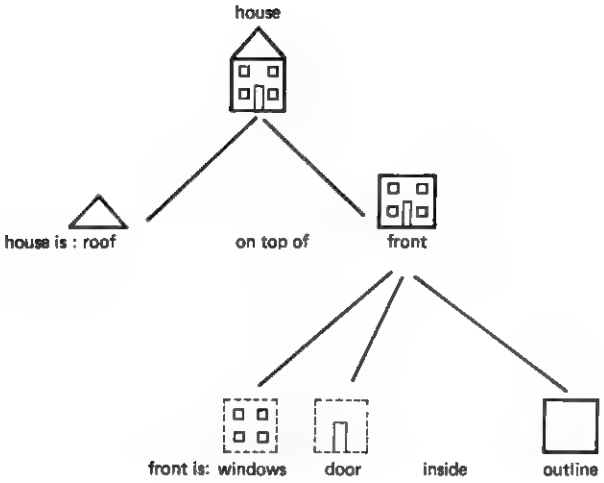
2 Extend the irregular polygon fill program (above) to include a scan of the data to find an interior point.

3 Draw a checker board or games board pattern using colour fill.

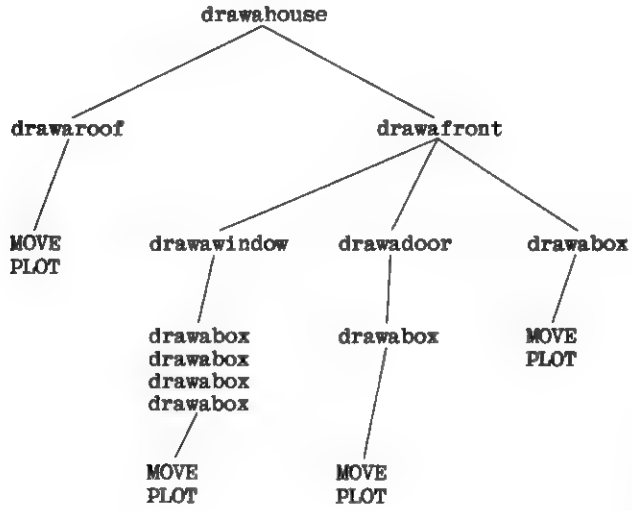
Object hierarchy

A large set of line drawings exhibit a hierarchy that can be usefully and profitably reflected in programs that produce line drawings. An electronic diagram, for example, is made up of resistors, capacitors and transistors. A resistor is made up of a line plus a rectangle plus a line:

A rectangle is made up of four lines. This may seem a rather trivial statement of the obvious but such an approach can lead to powerful programming techniques. Let's look at another simple example that may demonstrate the point. A child's stylisation of a house (which is after all a simple reflection of an adult's stylisation), can be structured hierarchically as follows:



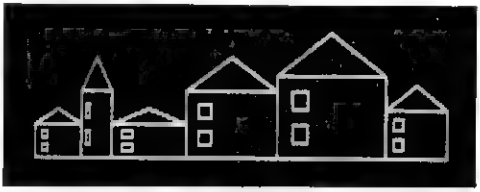
You can perhaps see from this that windows, doors and outlines are all rectangles of different sizes bearing certain spatial relationships to each other and can all use the same program module or procedure. The object hierarchy in the above tree is reflected in the procedure hierarchy in the next program.



```
 10   MODE 0
 20   x = 0 : y = 0
 30   FOR house = 1 TO 6
 40     MOVE x, y
 50     INPUT hs, vs
 60     PROCdrawahouse(hs, vs)
 70     x = x + hs * 30
 80   NEXT house
 90   END

100   DEF PROCdrawahouse(hs, vs)
110     PROCdrawafront(hs, vs)
120     PROCdrawaroof (hs, vs)
130   ENDPROC

140   DEF PROCdrawafront(hs, vs)
160      PROCdrawabox(hs*30, vs*30)
170      PROCdrawwindows(hs, vs)
180      PROCdrawadoor
190   ENDPROC

200   DEF PROCdrawabox(h, v)
210     PLOT 1, h,0
220     PLOT 1, 0, v
230     PLOT 1, -h, 0
240     PLOT 1, 0, -v
250   ENDPROC

260   DEF PROCdrawaroof(hs, vs)
270     PLOT 0, hs*30, vs*30
280     PLOT 1, -hs*15, vs*15
290     PLOT 1, -hs*15, -vs*15
300   ENDPROC

310   DEF PROCdrawwindows(hs, vs)
320     wh = hs*30/7 : wv = vs*30/5
330     PLOT 0, wh, wv
340     PROCdrawabox(wh, wv)
350     MOVE x, 0
360     PLOT 0, wh, 3*wv
370     PROCdrawabox(wh, wv)
380     MOVE x, 0
390   ENDPROC

400   DEF PROCdrawadoor
410   ENDPROC
```

Thus the procedure 'drawahouse' contains two procedure calls - 'drawaroof' and 'drawafront'. 'Drawaroof' does not need any further definition and contains only references to PLOT. 'Drawafront' contains three procedure calls - 'drawwindows', 'drawadoor' and 'drawabox'. 'Drawwindows' itself contains 4

calls of 'drawabox'. 'Drawabox' contains only MOVE and PLOT. Technically MOVE and PLOT are primitives or procedures that cannot be further defined and are the leaves of the tree. The program builds a hierarchy on MOVE and PLOT that reflects the hierarchy in the picture. We can only scratch at the surface of this particular topic and the power of the approach. This particular program will generate a street of six houses; the user types six pairs of data: the horizontal and vertical scale for each house. (To keep the program length down we have missed out two windows and the door procedure is empty.)



Finally although advanced techniques exist to handle the spatial relationships (windows are a set of four boxes inside another box for example), these are outside the scope of this text and have been handled in an empirical or ad hoc manner, by controlling the start coordinate of each house.

Exercises

1 Complete the house drawing program by adding detail of your choice to the hierarchy. For example windows can contain panes (a loop of boxes within a box), roofs can have chimneys, doors can contain letter boxes etc.

2 Add variety to the above skyline by including different objects that exhibit a similar hierarchy and use the same sub-pictures and primitives. For example an office block is a rectangle containing an array of rectangles; a church is a rectangle and triangle (steeple) with the triangle in a different spatial relationship compared with the house etc.

9.4 The GCOL statement : image planes

The GCOL statement not only sets up the graphic colour as we have already seen, but provides powerful logical processing facilities that can be used in a wide variety of graphics applications. Some of these are developed in the remainder of this chapter and others are utilised in the chapter on animation. Without such logical facilities many advanced graphics applications would be impossible. The GCOL facilities are as follows:

GCOL 0, colour	any subsequent plotting will be in the specified colour
GCOL 1, colour	the colour that results from subsequent plotting is produced by performing an OR operation between the specified colour and the existing screen colour at a pixel
GCOL 2, colour	as 1 but the logical operation is AND
GCOL 3, colour	as 1 but the logical operation is EOR (exclusive OR)
GCOL 4, colour	as 1 but the logical operation is NOT (i.e. the colour at any pixel visited is inverted)

GCOL 0 is straightforward and has already been introduced. The application of logical operations such as OR, AND, EOR and NOT is explained in Appendix 5. The rules concerning foreground and background colour are the same as for the COLOUR statement (colour number greater than 127 defines the graphics background colour).

Incidentally, the statement CLG (CLear Graphics area) can be used to clear the current graphics window and set it all to the current graphics background colour (selected by GCOL). CLS on the other hand clears the current text window and sets it to the current text background colour (selected by COLOUR).

GCOL 1 and 2 have applications in the dividing of an image into planes such as foreground, background and midground and GCOL 3 and 4 have applications in interaction described below.

We shall start by considering multi-plane images. A multi-plane image is an abstraction for the convenience of the programmer. He can build up images independently in planes that are (virtually) separate. This is useful in animation (below) and in being able to deal with a composite image, where different planes have a different priority, e.g. foreground, midground and background (below). We look first at the easier problem of constructing separate planes and switching between them, and then at the more general problem of building up a composite image from planes of different priority.

Virtual image planes : separate images

In a four-colour mode, two bits per pixel are used in the computer screen memory. However it is up to the programmer how he uses them. We could set up a scheme where we have two 'independent' planes or a scheme where we have a foreground and a midground plane of the same image. Consider the former scheme. We can set up the two bits at a pixel as follows:

```
0 = 00 = image1 and image2 background
1 = 01 = image1 foreground
2 = 10 = image2 foreground
3 = 11 = image1 and image2 foreground
```

The fourth code (3=11) is necessary to signify that for a particular pixel both image1 and image2 planes are 'on'. Starting with the easier consideration of switching between planes (assuming that both images are already built up) we would proceed as follows:

```
DISPLAY image1:

  VDU 19, 0, backgroundcolimage1, 0,0,0
  VDU 19, 1, foregroundcolimage1, 0,0,0
  VDU 19, 2, backgroundcolimage1, 0,0,0
  VDU 19, 3, foregroundcolimage1, 0,0,0
```

Image2 is thus set to the background colour selected for image1 and becomes invisible.

```
DISPLAY image2:

  VDU 19, 0, backgroundcolimage2, 0,0,0
  VDU 19, 1, backgroundcolimage2, 0,0,0
  VDU 19, 2, foregroundcolimage2, 0,0,0
  VDU 19, 3, foregroundcolimage2, 0,0,0
```

Now image1 is set to the background colour selected for image2 and becomes invisible.

To plot in the image1 plane, say, we have to proceed as follows for each pixel:

```
0 = 00 becomes  01
1 = 01 remains  01 (point already there)
2 = 10 becomes  11 (image2 point already there)
3 = 11 remains  11 (image2 and image1 point
                                  already there)
```

The third column is produced by ORing (inclusive) 01 with the second column and we simply precede any plotting statements with the appropriate GCOL statement:

PLOT image1: precede PLOT statements with GCOL 1, 1

Similarly to plot in the image2 plane:

```
0 = 00 becomes 10
1 = 01 becomes 11
2 = 10 remains 10
3 = 11 remains 11
```

and the appropriate GCOL is:

PLOT image2: precede PLOTs with GCOL 1, 2

The following program builds up a simple image in each image plane then repeatedly switches between them.

```
 10  MODE 5
 20  PROCplotimage1
 30  PROCplotimage2
 40  FOR screen = 1 TO 10
 50    PROCdisplayimage1
 60    PROCdelay
 70    PROCdisplayimage2
 80    PROCdelay
 90  NEXT screen
100  END

110  DEFPROCplotimage1
120    GCOL 1, 1
130    PROCdrawacircle(500, 500, 125)
140  ENDPROC

150  DEFPROCplotimage2
160    GCOL 1, 2
170    PROCdrawatriangle(327, 400, 346)
180  ENDPROC

190  DEFPROCdisplayimage1
200    VDU 19, 0, 2, 0,0,0
210    VDU 19, 1, 1, 0,0,0
220    VDU 19, 2, 2, 0,0,0
230    VDU 19, 3, 1, 0,0,0
240  ENDPROC
```

```
250   DEFPROCdisplayimage2
260     VDU 19, 0, 4, 0,0,0
270     VDU 19, 1, 4, 0,0,0
280     VDU 19, 2, 0, 0,0,0
290     VDU 19, 3, 0, 0,0,0
300   ENDPROC

310   DEFPROCdrawacircle(xc, yc, r)
320     MOVE xc + r, yc
330     FOR theta = 10 TO 360 STEP 10
340       x = r*COS(RAD(theta))
350       y = r*SIN(RAD(theta))
360       x = xc + x : y = yc + y
370       MOVE xc, yc : PLOT 85, x, y
380     NEXT theta
390   ENDPROC

400   DEFPROCdrawatriangle(xs, ys, s)
410     MOVE xs, ys : DRAW xs+s, ys
420     PLOT 85, xs+s/2, ys+s*0.866
430   ENDPROC

440   DEF PROCdelay
450     TIME = 0
460     REPEAT : UNTIL TIME>100
470   ENDPROC
```

In the above note that we are using completely different colours in each image. Switching between image planes that use the same colour is important in animation (Chapter 11).

Incidentally information common to both planes (such as text, say), need only be plotted once using GCOL 0, 3.

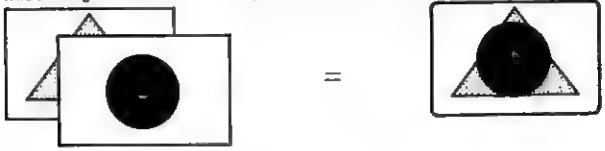
Composite image with priority

Again with a choice of four colours the above scheme can easily be adapted to set up a three-plane composite image (foreground, midground and background). Using GCOL the foreground and midground planes can be independently accessed and anything drawn in the midground plane that is shadowed by anything drawn in the foreground plane is automatically obscured in the composite image. Also we can delete from the foreground, delete from the midground, add to the foreground or add to the midground and the foreground/midground priority is automatically taken into account. Common operations that we might want to perform are:

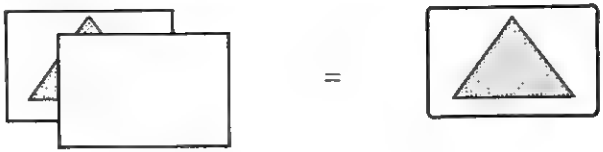
Logical image planes *Composite display image*

(The figures are meant to be solid or filled)

Initial image—a circle in the foreground against a triangle in the midground

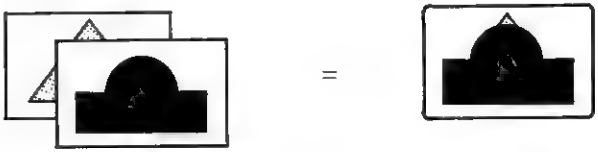


Delete foreground from initial image



Delete midground from initial image

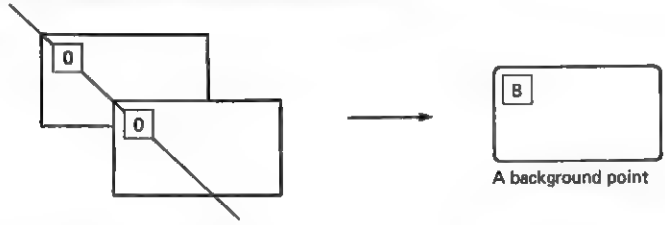
Add to foreground in initial image



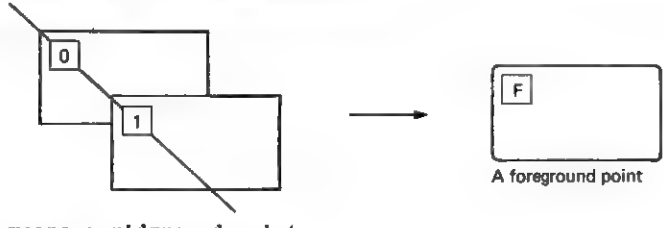
Add to midground in initial image

How this is accomplished is now explained. Suppose we are operating in a four colour mode (this allows two planes plus background). A four colour mode means that there are two bits per pixel, i.e. we can imagine the image memory as two one-bit planes.

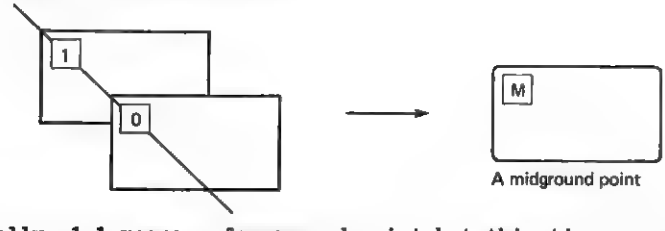
If the two planes have 0,0 in a pixel position, then the display image is a background point:



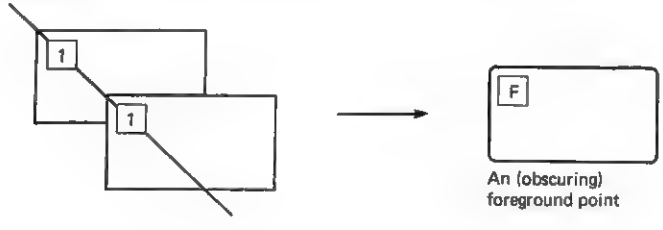
If the two planes have 0,1 in a pixel position then the display image is a foreground point



1,0 means a midground point



Finally 1,1 means a foreground point but this time one that is obscuring a midground point



Thus we have:

```
0 = 00 = background   point (. in illustrations)
1 = 01 = foreground   point (F in illustrations)
2 = 10 = middleground point (M in illustrations)
3 = 11 = foreground   point (F in illustrations)
         (obscuring a midground)
```

Note that we use two logical colour codes to represent the foreground. This is because we can have 2 types of foreground points - a foreground point obscuring a background point only, and a foreground point obscuring a midground point. We can now give a few examples of 'plane' plotting and you can generalise from these examples.

To PLOT in the foreground

We precede any plot statements with GCOL 1,1 (inclusive OR):

```
GCOL 1,1
PLOT statements to plot figures in foreground plane
```

Now because

```
    00        OR        01        =        01
background          foreground          foreground
```

background points are obscured by foreground points:

```
....................
....FFFFFFFFFFFF....
....F...............
....F...............
....FFFFFFFFFF......
....F...............
....F...............
....F...............
....................
```

To PLOT in the midground

We precede any PLOT statements with GCOL 1,2 (inclusive OR):

```
GCOL 1,2
PLOT statements to plot a figure in the midground plane
```

Now because

```
     00        OR        10        =        10
background          midground           midground
```

and

```
        01       OR       10       =        11
  foreground          midground          foreground
```

background points are obscured by midground points as you would expect but points that are are already foreground remain in the foreground colour (but with code 11 indicating that they are obscuring a midground point). Thus to build up information in these two planes we use GCOL 1 (inclusive OR).

```
....................
....FFFFFFFFFFFF.....
....FM........MM.....
....F.M......M.M.....
....FFFFFFFFFF.M.....
....F...M...M...M....
....F....M.M....M....
....F.....M.....M....
....................
```

You can perhaps see from this that after a composite set of planes has been built up any subsequent additions to the foreground or midground will be incorporated into the composite image according to their respective priority.

To DELETE from foreground and midground

Now to delete images or parts of images from planes we use GCOL 2 (AND). To delete a foreground object, we redraw the object after using GCOL 2,2, where the second parameter happens to be the midground colour but is used here as a "foreground delete code". To delete a midground object, we use GCOL 2,1. For example to delete from the foreground:

```
GCOL 2, 2
PLOT statements to delete figure from foreground plane
```

and the PLOT statements will be exactly the same as the ones that were used to draw the object being deleted. Now we have

```
      00       AND      10      =      00
  background                          background
```

i.e. background points remain as background

```
      01       AND      10      =      00
  foreground                          background
```

'ordinary' foreground points revert to background

```
    10      AND    10    =     10
midground                    midground
```

'ordinary' midground points are left unaltered

```
    11      AND    10    =     10
```

'obscured' midground points are now revealed

```
....................
....M..........M.....
....MM........MM.....
....M.M......M.M.....
....M..M.....M..M....
....M...M...M...M....
....M....M.M....M....
....M.....M.....M....
....................
```

Thus GCOL 2 (AND) can be used to delete and reveal. These operations are now demonstrated. The procedures are left undefined (see earlier sections) but should include colour fill. The following program draws a red circle in the foreground plane and a yellow triangle in the midground plane and any geometrical overlap is automatically taken care of. Note line 20; remember that we use 2 codes for the foreground and these of course should be the same colour.

```
10   MODE 5
20   VDU 19, 3, 1, 0,0,0
25   GCOL 1, 1
30   PROCdrawacircle(500, 500, 125)
40   GCOL 1, 2
50   PROCdrawatriangle(327, 400, 346)
60   END
```

To delete the red circle and reveal any previously hidden parts of the yellow triangle we can add:

```
60   keypress = GET
70   GCOL 2, 2
80   PROCdrawacircle(500, 500, 125)
```

which 'undraws' the circle.

A convenient alternative to the above uses of GCOL 1 and GCOL 2 is often useful. Provided that an object being plotted in a plane does not overlap any object that is already present in that plane, then GCOL 3 can be used for

both the drawing and deleting process. For example to draw an object in image plane 1:

```
GCOL 3, 1
PLOTs etc to draw the object
```

To delete the object we simply repeat exactly the same GCOL and PLOT statements.

In MODE 2, we have 4 bit colour codes (16 colours) and this gives us many more possibilities. One possibility would be to have image planes with:

```
3 foreground colours     (spaceships?)
1 frontmidground colour  (planets?)
1 rearmidground colour   (stars?)
1 background colour      (sky?)
```

The details of how to do this are beyond the scope of this introductory text but you might try and work out how to do it yourself.

Exercises

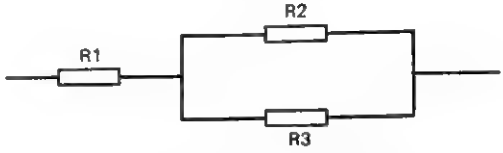
1 Undraw a rectangle by working from the centre as if it were a stage curtain being pulled to each wing. Underneath should reveal detail in another colour: legendry that might be used in a caption sequence or anything else you fancy.

2 Plot two pictures using values from DATA statements and then repeatedly read a key. Depending on which key was pressed, display the first picture or display the second picture or display both pictures at once (without re-drawing them).

9.5 Basic interaction techniques (GCOL 3 and GCOL 4)

In this section two interaction techniques are implemented. Both of these use the keyboard, but clearly the principles are the same for either a keyboard or a more convenient device. Both interaction techniques can be used in picture construction and this forms a part of most CAD (Computer Aided Design) systems. Such techniques enable designers to work in a two-dimensional or picture domain. This means for example that an electrical engineer can work with circuit diagrams and an architect with elevations or other projections of buildings, rather than just numbers. Now CAD techniques are an extensive topic by themselves and we shall only be concerned here with picture or line-drawing generation. It is not out of place to examine just briefly how such techniques 'fit in' to CAD programs. A CAD program that accepts a picture as input has to deduce certain information from it. An electrical engineer may draw a

circuit diagram as input. A simple but somewhat unrealistic example serves to illustrate the point; say he inputs a series parallel resistor configuration:

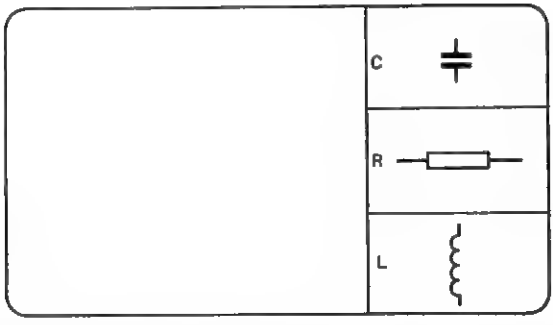


From this the CAD program will have to deduce that a resistor is connected in series to two resistors in parallel and that the total resistance is :

$$RT = R1 + R2*R3/(R2 + R3)$$

It can then evaluate numerical calculations and output required information graphically or otherwise back to the user. The CAD program will also be able to cope with alterations to the diagram - additions, deletions etc.

In the same way an architect may sketch in the elevations of a house and ask for costing, insulation or sunlight calculations. If we return to the circuit diagram, this is something that would be built up using a technique known as 'picking and dragging' (below) A user is presented with a menu of objects and he can pick or select a particular object and drag it to anywhere on the screen:



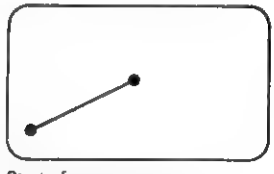
Other operations that might be available on objects are magnification and rotation. Again in the case of an electrical circuit diagram, in parallel with the picture-drawing modules there will be procedures that keep track of the spatial relationship between components. The CAD program can then build up a formula reflecting some required attribute or behaviour of the circuit. This might be

transfer characteristic, frequency response, etc. The computer program's view of the problem is numerical or formula based while the engineer's view remains pictorial. This is a tremendous advantage in most design problems.

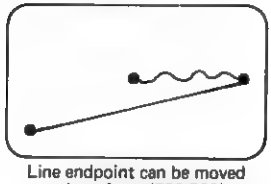
In the next two sections we look at the front end of such CAD programs firstly by looking at how we can sketch line drawings on the screen, and secondly how we can pick and drag predefined sub-pictures across the screen.

Rubberband line drawing

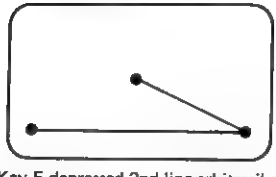
Using this technique we can build up a sketch or line drawing on the screen, using line segments whose length and direction are controlled from the keyboard. The program starts off by drawing an arbitrary line from (0,0) to (500,500). By using keys R, L, U, and D (Right, Left, Up and Down) as direction indicators we can move the end point of the line anywhere we want. Key F can be used to 'Fix' the end point of the line.



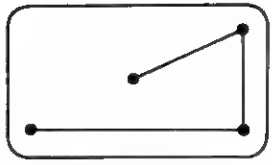
Start of program
Arbitrary line drawn from (0,0) to (500,500)



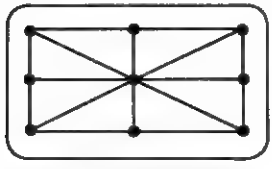
Line endpoint can be moved anywhere from (500,500)



Key F depressed 2nd line arbitrarily drawn to (500,500) and 1st line permanently drawn



This line can be moved anywhere
and key F depressed again



Thus any shape can be built up

The program is as follows:

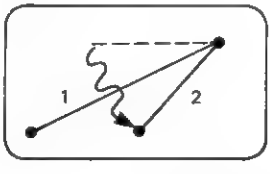
```
 10   MODE 4
 20   xs = 0 : ys = 0
 30   x = 640 : y = 512
 40   GCOL 3, 1
 50   PROCdrawordelete
 60   REPEAT
 70     command$ = GET$
 80     PROCprocesscommand
 90   UNTIL command$ = "Q"
100   MODE 6 : END

110   DEF PROCprocesscommand
120     IF INSTR("FLRUD",command$) = 0 THEN ENDPROC
130     IF command$ = "F" THEN PROCfix
                          ELSE PROCdrawordelete
140     IF command$ = "L" THEN x = x - 5
150     IF command$ = "R" THEN x = x + 5
160     IF command$ = "U" THEN y = y + 5
170     IF command$ = "D" THEN y = y - 5
180     PROCdrawordelete
190   ENDPROC

200   DEF PROCdrawordelete
210     MOVE xs, ys : DRAW x, y
220   ENDPROC
```

```
230   DEF PROCfix
240     REM Permanent draw to fill in gaps where
250     REM moving line crosses existing lines.
260     GCOL 0,1 : PROCdrawordelete
270     GCOL 3,1
280     xs = x : ys = y
290     x = 640 : y = 512
300   ENDPROC
```

'xs' and 'ys' always represent the start position of the line currently being drawn and 'x' and 'y' represent the position of the end of the line being moved. The program consists of a REPEAT loop that processes commands UNTIL the key Q (Quit) is typed.

PROCprocesscommand first checks for a valid key. If "F" has been pressed, then the line currently being operated on is fixed and the coordinates are set for a new line. Otherwise a call of PROCdrawordelete is used to delete the current line in preparation for redrawing it in a new position. One of the coordinates x, y is updated if one of the movement keys (L, R, U, D) has been pressed. PROCprocesscommand terminates by drawing a line to the position now specified by the x-y coordinates.

The critical statement in the program is GCOL 3, 1 (exclusive OR). This means that lines can be moved over existing lines without permanently wiping part of them out, as would be the case without this facility. Normally to delete an object we would re-plot the object in the background colour but this would wipe out intersecting parts of existing lines. Using the above method, an existing line disappears only momentarily while the current moving line passes over it.



Thus line segment 2 (above) can be swept over existing line segment 1 without rubbing it out. This can be explained by reference to the following table.

	1st. DRAW			2nd. DRAW	
old	plotting	new	old	plotting	new
0	1	1	1	1	0
1	1	0	0	1	1

You can see from the bottom row of the table that plotting a 1 on top of a 1 in the first DRAW results in a zero that is restored to a 1 by the 2nd DRAW. The top row of the table gives the effect of a normal draw and erase function. The second DRAW thus erases or undraws, at the same time restoring any holes in existing lines made by the 1st DRAW. We leave it as an exercise to work out why the behaviour is unaltered if GCOL 3 is replaced by GCOL 4.

Picking and dragging an object

We have already mentioned the use of this particular technique above so we'll jump straight in to doing it. In the next program we have set up a triangle in a corner of the screen. This can be moved anywhere using keys L, R, U, and D as before. When the final positioning is achieved key F is pressed to establish the object in that position.

```
 10  MODE 4
 20  x = 0
 30  y = 0
 40  GCOL 3, 1
 50  PROCdrawatriangle(x,y)
 60  REPEAT
 70    command$ = GET$
 80    PROCprocesscommand
 90  UNTIL command$ = "Q"
100  MODE 6 : END

110  DEF PROCprocesscommand
120    IF INSTR("FLRUD",command$) = 0 THEN ENDPROC
130    IF command$ = "F" THEN PROCfix
                         ELSE PROCdrawatriangle(x,y)
140    IF command$ = "L" THEN x = x - 5
150    IF command$ = "R" THEN x = x + 5
160    IF command$ = "U" THEN y = y + 5
170    IF command$ = "D" THEN y = y - 5
180    PROCdrawatriangle(x,y)
190  ENDPROC

200  DEF PROCfix
210    GCOL 0,1 : PROCdrawatriangle(x,y)
220    GCOL 3,1
230    x = 0 : y = 0
240  ENDPROC

250  DEF PROCdrawatriangle(x,y)
260    MOVE x, y
270    PLOT 1, 60, 0 : PLOT 1, -30, 30
280    PLOT 1, -30, -30
290  ENDPROC
```

The program to drag an object is identical to the rubberband program (which drags the end of a line) except that every occurrence of:

```
PROCdrawordelete
```

is replaced by:

```
PROCdrawatriangle(x, y)
```

Picking can be accomplished easily. For example if there were 2 objects, every occurrence of:

```
PROCdrawatriangle(x, y)
```

is now replaced with:

```
PROCdrawashape(x, y, pick$)
```

where 'pick$' is a character code indicating the shape currently selected. PROCdrawashape is defined as:

```
300   DEF PROCdrawashape(x, y, p$)
310     IF p$="T" THEN PROCdrawatriangle(x, y)
320     IF p$="B" THEN PROCdrawabox(x,y)
330   ENDPROC
```

The variable 'pick$' contains one of the codes "T" for Triangle, or "B" for Box. At the start of the program 'pick$' is set by

```
45   PROCpick
```

and in PROCfix by

```
235     PROCpick
```

where PROCpick is defined as

```
350   DEF PROCpick
360     PRINT TAB(0,0); "Pick, (T/B)";
370     pick$ = GET$
380     PRINT TAB(0,0); "            ";
390   ENDPROC
```

PROCdrawabox is straightforward.

Other common facilities in picking and dragging programs are magnification and rotation. For example in the above dragging program, a 5th key option could be "M" for

'Magnify'.

```
DEF PROCprocesscommand
          .
          .
          .
  IF command$ = "M" THEN scale = scale*1.2
  PROCdrawatriangle(x, y, scale)
ENDPROC
```

PROCdrawatriangle would now be defined as:

```
250   DEF PROCdrawatriangle(x, y, scale)
260     MOVE x, y  :  PLOT 1, 60*scale, 0
270     PLOT 1, -30 * scale, 30 * scale
280     PLOT 1, -30 * scale, -30 * scale
290   ENDPROC
```

The variable 'scale' would be initialised to 1 at the start of the program. Note that the scale is increased by 20 per cent for magnification so that the increase in the scale is proportional to the current size of the triangle. Also 'scale' needs to be reset to unity after each triangle has been moved, magnified and established. We leave the alterations needed for rotation as an exercise.

Saving a line drawing

An image that has been created by rubberbanding can be saved as a list of coordinates and subsequently regenerated by a simple program reading the coordinates from a file and using DRAW. The coordinates can be saved initially in two parallel arrays and when the drawing is complete, the array contents dumped into a file. The coordinate saving should clearly be part of the 'fixing' process:

```
230   DEF PROCfix
260     GCOL 0,1 : PROCdrawordelete
270     GCOL 3,1
280     line = line + 1
290     xcoord(line) = x
300     ycoord(line) = y
310     xs = x : ys = y
320     x = 0 : y = 0
330   ENDPROC
```

Similarly an image that has been created by picking and dragging an object can be saved, most economically, using

three parallel arrays. The program would store, for each object, a pair of coordinates followed by a code indicating the class of object drawn at that position. The program would terminate by outputting the contents of the three arrays to a file. The regenerating program would contain the object-generating procedures again called from a shape selection procedure, the appropriate procedure for each shape being selected according to the stored code.

Exercises

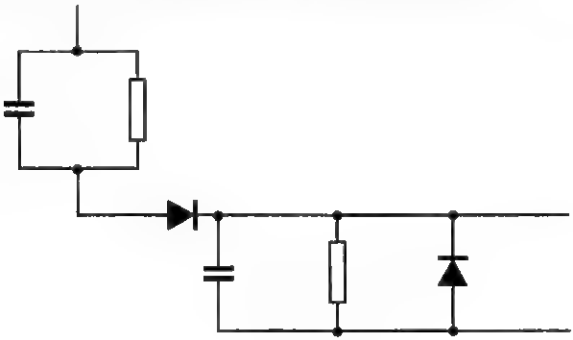
1 Improve the rubber band program so that the start coordinate is input from the keyboard.

2 Introduce colour so that the fixed lines are displayed in one colour, but the moving line appears in a contrasting colour.

3 Write a rubber band program where the permanent lines are to be constrained to the horizontal or vertical direction. For example an imperfectly drawn horizontal line:

is to be corrected to a perfect horizontal line:

4 Write a picking and dragging program that will allow such diagrams as the following to be constructed:



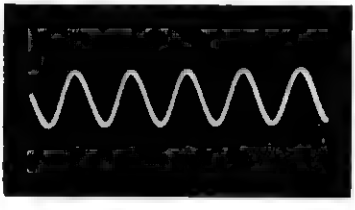
Note that this will have to contain both object dragging and rotation (0 or 90 degrees only) as well as rubberband line drawing.

5 Incorporate the picture-filing suggestions in one of your programs.

Chapter 10 Sound

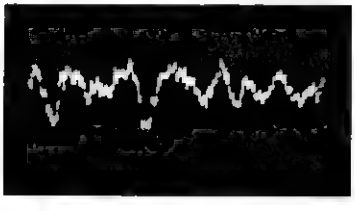
10.1 Sound and pitch

Perhaps it is best to introduce you to sound by tying up the aural impressions or qualities of various sounds with visual impressions. Any sound is caused by a pressure variation with time, or successive compressions and rarefactions of air. This pressure variation can be converted into a variation of electrical current as a function of time, using a transducer such as a microphone, and the electrical current or signal displayed on an oscilloscope. This gives us an idea of what sounds look like when converted into such a signal. 'Seeing' sounds then provides us with a useful bridge between the aural impressions of sounds and the hard numbers that we have to supply to a computer program in order to to generate the sounds. Various examples are shown in the photographs below.

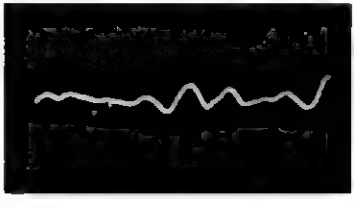


A pure tone: Middle C

The same tone as generated by the Electron



An extract from rock music



An extract from a nearly monotonic section of Eric Satie's music

A pure tone has a regular sinusoidal appearance and can only be generated perfectly by electronic means or by mechanical

(or electromechanical) devices such as tuning forks. Musical instruments do not generate pure tones but a complex mixture of pure tones, each mixture a function of many variables, the most predominant being the instrument type and the player. An oboe produces a mellow smooth tone, a trumpet a much harsher cutting tone.

The basic sound generated by the Electron is not a pure tone either. It is a distorted square wave (see illustration) and this is why it sounds 'electronic'. Its other less than desirable characteristic is that it changes shape as a function of frequency or pitch. This means that the character of the sound changes with frequency.

The Electron can generate tones of specified pitch, and these can be used to play simple tunes. Using the ENVELOPE statement, we can enhance the sounds made with the cacophonous effects usually associated with arcade games. Such effects have been left to the end of the chapter because they can only be fully appreciated after the other facilities have been covered. You can however jump ahead, read some of the material on the ENVELOPE facilities, and then use them in earlier programs.

10.2 The SOUND statement

The SOUND statement allows us to manipulate three basic parameters of a single tone sound waveform: the frequency or pitch, the amplitude or loudness and the duration of the sound. A SOUND statement is written as:

```
SOUND   C, A, P, D

where   C is the channel number
        A  is the amplitude
        P is the pitch number
        D is the duration
```

Channel

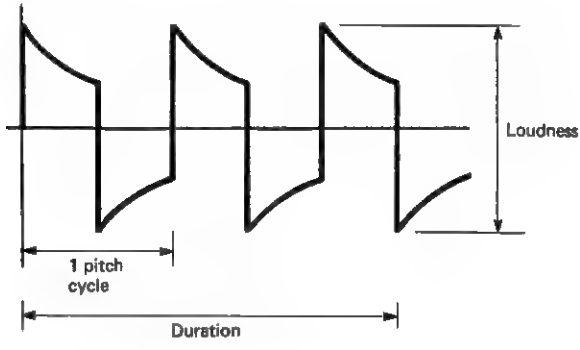
If C is set equal to 0 then various noises can be produced. This facility is described at the end of the chapter. For tones, C is set to 1, 2 or 3.

When the computer obeys a SOUND statement, it adds the sound request to a queue of such requests. The statements waiting on the queue are ordered according to their channel number. Notes with lower channel numbers are played first. The use of this facility is illustrated in the next section.

Amplitude

As we saw in Chapter 1, A, the amplitude, can have a negative value ranging from 0 for silence down to -15 for maximum loudness. The complete range is from -15 to 4 and the use of the 4 positive integers is explained later in the

section on the ENVELOPE statement. Note that A specifies the amplitude of an electronically generated waveform. Even although A = -14 generates a wave twice the amplitude (or voltage) of a wave for A = -7, it does not sound twice as loud. This is because the human ear has a logarithmic response to loudness. We show below how these parameters relate to the actual waveform generated by the sound synthesiser.

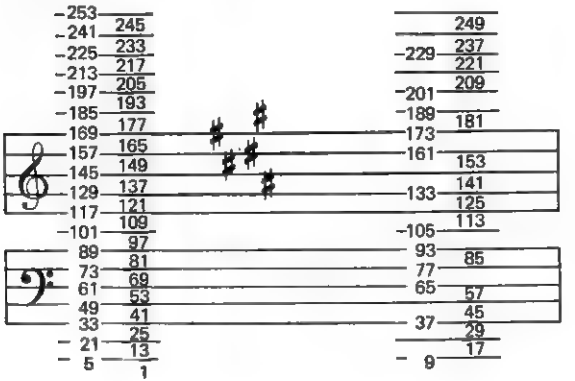


Pitch

The pitch, or frequency, of a note is the number of undulations or cycles per unit time, where a complete undulation is a positive and a negative hump. The range of basic square wave tones that can be generated on your computer spans 5 octaves and the frequency of each tone is specified by a so-called pitch number, P. (An octave is a doubling of frequency or pitch.) The pitch numbers are the values that have to be inserted in the SOUND statement pitch parameter to produce the required note. In the next diagram, the pitch number information has been reproduced in 3 equivalent forms, musical stave, piano keyboard and table. The musical stave has been transposed by one octave for convenience. All are equivalent and you should use the one that you are comfortable with. The pitch numbers are not the actual frequencies of the notes; for example middle C is specified by a pitch number of 53 but has an actual frequency around 261 Hz.

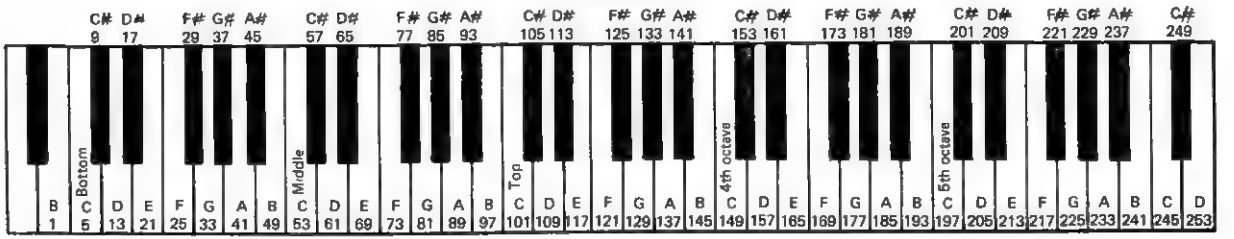
Note that there are four integers between each note (row) in the table. In western music an octave is divided into 12 equal semitones. With the sound synthesiser in the Electron 4 more intervals are available between each semitone so the smallest interval that can be specified is a quarter semitone. This means that there are 48 intervals available in an octave. In the first part of this chapter we will only be concerned with 'musical' sounds and so we'll stick to values of pitch number given in the table.

Stave diagram (transposed one octave)



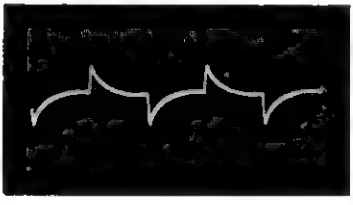
NOTE												OCTAVE NO
C	C#	D	D#	E	F	F#	G	G#	A	A#	B	
											↑	
5	9	13	17	21	25	29	33	37	41	45	49	1
53	57	61	65	69	73	77	81	85	89	93	97	2
101	105	109	113	117	121	125	129	133	137	141	145	3
149	153	157	161	165	169	173	177	181	185	189	193	4
197	201	205	209	213	217	221	225	229	233	237	241	5
245	249	253										6

Keyboard diagram

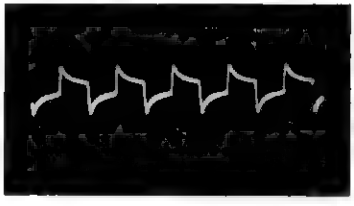


Duration
D, the duration of the sound, is an integer in the range 0 to 254 and specifies a duration value in twentieths of a second. D=254 is the maximum controlled duration and D=255 means that the sound continues indefinitely.

Here, two SOUND statements are shown together with the waveform that they generate.



SOUND 1, -15, 100, 255



SOUND 1, -15,200, 255

Using the basic SOUND statement is very easy as the next program demonstrates.

```
 10   MODE 1
 20   VDU 19, 3, 4; 0;
 30   GCOL 0, 1
 40   SOUND 1, -12, 53, 200
 50   PROCdrawsine(4, 300)
 60   GCOL 0, 2
 70   SOUND 1, -12, 69, 200
 80   PROCdrawsine(5, 200)
 90   GCOL 0, 3
100   SOUND 1, -12, 81, 200
110   PROCdrawsine(6, 100)
120   END

130   DEF PROCdrawsine(freq, amp)
140   VDU 29, 0; 500;
150   MOVE 0, 0
160   yscale = amp
180   FOR x = 0 TO 1000 STEP 10
190     y = SIN(RAD(freq*x))
200     DRAW x, y*yscale
210   NEXT x
220   ENDPROC
```

The program generates 3 consecutive notes C, E and G. The frequency relationship of E to C is 5:4 and G to C 3:2. Taken together the 3 notes make up a pleasing harmony known as a major triad. The intervals in pitch between C, E and G form a chord that is pleasant to listen to. The purpose of

the program is to demonstrate the effect of the frequency and duration parameters in the SOUND statement. The program generates the note C and plots a sine wave; then it generates E and a corresponding sine wave, with the frequency increased in the ratio 5:4 relative to that for C; finally it generates G, plotting another sine wave with the frequency increased again in the ratio 3:2 relative to that for C. The sine waves are drawn at different amplitudes to enhance clarity. The sounds are all at the same loudness. The duration of each note should be the time taken for each sine wave to be plotted. A duration of 10 seconds or D = 200 gives a reasonable result.

10.3 Synchronisation of sounds with other events

We frequently require the start or finish of a sound to be accurately synchronised with another program event. In the above program, the sounds are approximately synchronised with the plotting of the sine waves, but the sound durations required for this were obtained by trial and error. We estimated the duration of each note at 10 seconds or D = 200 However, see what happens if you make D = 250. Here there is no synchronisation between the sound and the graph. This is because the second SOUND statement is encountered by the computer before the first has finished. Similarly the third is encountered before the second has finished. In this situation the second and third sounds are placed in a queue (because they cannot be sounded at the instant the SOUND statements are obeyed) and the computer carries on to draw the next sine wave. Each sound continues for its specified duration. In this section, we look at two ways of accurately synchronising sounds with other events.

Channel priority

In general it would be more convenient to make the program terminate the previous note and initiate the next note when it is ready to start plotting each sine wave. This can be accomplished by using the channel priority mechanism.

If a sound is being played on channel 3, say, and a SOUND statement is obeyed for a lower channel number (0, 1 or 2), then the channel 3 sound is terminated immediately because a sound with lower channel number takes priority. Thus the notes produced in the above program by the statements

```
 40   SOUND 1, -12, 53, 200
 70   SOUND 1, -12, 69, 200
100   SOUND 1, -12, 81, 200
```

are approximately synchronised from guesswork. If we lengthen the notes by making the changes

```
 40   SOUND 1, -12, 53, 250
 70   SOUND 1, -12, 69, 250
100   SOUND 1, -12, 81, 250
```

the result is completely unsynchronised, whereas if we use

```
 40   SOUND 3, -12, 53, 255
 70   SOUND 2, -12, 69, 255
100   SOUND 1, -12, 81, 200
```

it is exactly synchronised because of channel priority. All we have done is to use an indefinite duration for the first two sounds and give the second and third sounds priority over the previous ones. When line 70 is executed, the sound started by line 40 is immediately terminated. Similarly when line 100 is executed the sound started by line 70 is immediately terminated. Each sound is initiated by the program as soon as it is ready to plot the corresponding sine wave.

Flushing a channel queue

Another way of terminating a sound prematurely is to use the operating system command *FX 21. For example, the command

```
*FX 21, 4
```

will 'flush' the channel 0 sound queue. This means that any sound currently being played on channel 0 will be terminated prematurely and any other sounds waiting to play on channel 0 will be removed from the queue and ignored. We also have:

```
*FX 21, 5     Flushes the channel 1 sound queue.
*FX 21, 6     Flushes the channel 2 sound queue.
*FX 21, 7     Flushes the channel 3 sound queue.
```

We can use this facility to synchronise the sounds with the drawing in the tonic triad program:

```
 40   SOUND 1, -12, 53, 255
 69   *FX 21, 5
 70   SOUND 1, -12, 69, 255
 99   *FX 21, 5
100   SOUND 1, -12, 81, 255
111   *FX 21, 5
```

10.4 Playing sequences of notes

There are three basic methods that can be employed to get your computer to play tunes. Firstly the tune can be incorporated in the program note by note as a DATA statement, with a pitch, duration and amplitude value for each note. Secondly you can play a tune by 'typing' keys on the keyboard, as if it were a keyboard instrument, and thirdly you can get the computer to make up tunes. The first method is rather tedious. The third method is potentially the most interesting and rewarding. It is necessary before moving on to the third method to develop certain techniques and these are most easily demonstrated by the first two methods: getting the computer to play DATA statements or playing a tune from the keyboard. Now all of the techniques described in this section can be enhanced by the use of the ENVELOPE statement so this section and the material on the ENVELOPE statement should be read in parallel; for clarity we have kept the material on generating sequences of notes separate from that on using ENVELOPE statements for modifying the sound of notes.

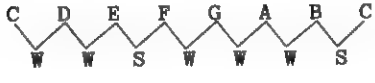
Generating scales

If you move on to using the computer as a composer then you will need a basis or a vocabulary for the music that you are going to generate. Unless your tastes incline towards the avant garde, then you will probably want to generate music in a particular style or feel. You might want to generate music with a 'folksy' feel or a jazz feel. One important basis or vocabulary that can be used is scales. A scale is also an easily generated fixed sequence of notes and it seems useful to start with scales. They do make a somewhat boring sound but bear in mind their potential usefulness when you work through this section.

A scale is a sequence of notes spanning an octave, i.e. a sequence terminating on the note an octave higher than the one it started on. The 'do, re, me,...' scale is a major scale and in the key of C is:

C D E F G A B C

A scale has a particular musical character (a minor scale is recognizably different from a major scale) and can be expressed as a series of semitone, whole tone or minor third (3 semitones) intervals. The C major scale intervals are:



W = Whole tone
S = Semitone

The major scale can be built on any starting note using the

above interval sequence so there are 12 major scales with the interval sequence

W W S W W W S

It is this interval sequence that imparts the musical character to a scale, not its starting note. A G major scale sounds like a C major scale except for being higher. Different musical forms tend to have notes that are selected from a particular scale. Folk music tends to have notes selected from the pentatonic scale. (Auld Lang Syne is made up entirely of notes from the pentatonic scale.) Jazz blues contain, predominantly, notes selected from a blues scale. A classical work in D-minor contains notes predominantly in the minor scale. It must be emphasised that this is only a first approximation, music is much more complex than this. Paradoxically one of the ways that the listener's interest in a piece of music is held is by creating tension, or selecting notes that do not belong to the underlying scale.

Now because a scale is a sequence of tones and semitones we can play a scale by inserting a SOUND statement in a FOR loop and reading from a DATA statement the tone-semitone sequence. The numbers in the DATA statement are a sequence of 12s, 8s, and 4s. An increment of 8 in the pitch number causes a whole tone interval, an increment of 4 a semitone and an increment of 12 three semitones or a minor third.

Thus a C major scale could be played by:

```
10   tone = 53
20   SOUND 1, -10, tone, 6
30   FOR note = 2 TO 8
40     READ interval
50     tone = tone + interval
60     SOUND 1, -10, tone, 6
70   NEXT note
80   DATA 8, 8, 4, 8, 8, 8, 4
```

The next program expands this idea and selects one out of n scales (3 shown in program). Each scale can be a different length and each DATA statement comprises a code (abbreviated scale name), a length, then the tone semitone sequence. The abbreviations used are wt: whole tone, dim: diminished and maj: major.

In the program PROCselect is a general procedure that could be used in any context where a particular DATA statement is to supply data to a process. Each DATA statement is preceded by a code to be matched with an input code. PROCselect simply swallows DATA statements until the required one is reached, leaving the READ 'pointer' or 'window' positioned on the length of the required scale. This structure is easily altered to a 'guess this scale'

program, selecting at random a DATA statement and checking a guess against the corresponding identification code.

```
 10   INPUT "Scale", scale$
 20   PROCselectscale(scale$)
 30   PROCplayscale
 40   END

 50   DEF PROCselectscale(scale$)
 70     REPEAT
 80       READ reqscale$
 90     UNTIL reqscale$ = scale$
100   ENDPROC

110   DEF PROCplayscale
120   READ slength
130   note = 53
140   SOUND 1, -10, note, 3
150   FOR i  = 2 TO slength
160     READ interval
170     note = note + interval
180     SOUND 1, -10, note, 3
190   NEXT i

200   DATA wt, 7, 8, 8, 8, 8, 8, 8
210   DATA dim,9, 4, 8, 4, 8, 4, 8, 4, 8
220   DATA maj,8, 8, 8, 4, 8, 8, 8, 4
```

The following is a list of common scales in the form of pitch number intervals corresponding to tone, semitone and minor third intervals.

Scale	Interval sequence
major	8 8 4 8 8 8 4
diminished	4 8 4 8 4 8 4 8
blues	12 8 4 4 12 8
Hindu	8 8 4 8 4 8 8
whole tone	8 8 8 8 8 8
dorian minor	8 4 8 8 8 4 8
aeolian minor	8 4 8 8 4 8 8
harmonic minor	8 4 8 8 4 12 4
pentatonic	8 8 12 8 12

Now all the scales have a different quality that is determined by the interval sequence. For example, the familiar major scale has a suspension on the B that you feel wants to resolve to the C or tonic note. Try playing this scale and stopping at the B.

As the program is written, the different scales all start from the same note - bottom C. Note that the sequences could

be built on any starting note:

```
 10   INPUT scale$, startnote
 20   PROCselectscale(scale$)
 30   PROCplayscale(startnote)
            :
130     note = startnote
```

We can thus change key easily. Also note that the speed at which the scales are played and the loudness can be similarly controlled by single parameters.

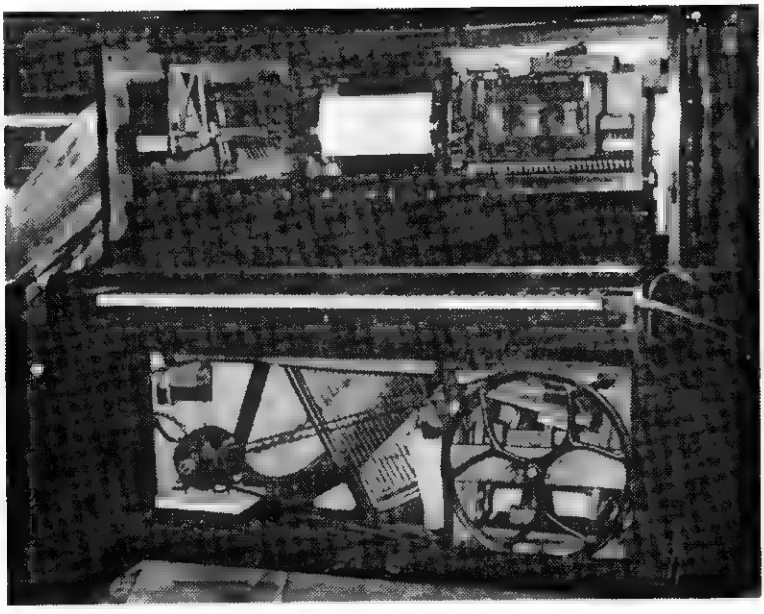
```
 10   INPUT scale$, startnote, notelength, vol
 20   PROCselectscale(scale$)
 30   PROCplayscale(startnote, notelength, vol)
            :
130    note = startnote
140    SOUND 1, vol, note, notelength
            :
180     SOUND 1, vol, note, notelength
```

Playing tunes from DATA statements

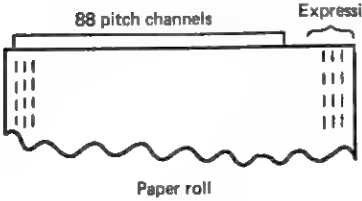
In this section we describe how you program the computer to play tunes from DATA statements. The programming itself is very simple and most of the work involved is in transcribing the music into a form suitable for input to a program.

Now you will never program the computer to produce a really musical performance, but you can have fun rearranging your favourite tunes and adding effects. A good analogy is a mechanical piano playing a tune from a paper roll. The performance is constrained by the limitations of the reproducing mechanism and the information on the paper roll. Basic mechanical pianos play music that sounds mechanical. More elaborate mechanical pianos are very good and practically indistinguishable from a live performance.

The point of this diversion is that the very elaborate reproducing pianos have much more information on the paper roll than do the basic ones. The same principle applies to the tune DATA statements - the more expression and variety that you wish to build into the tune, the more information must be loaded into the DATA statement for each note. The extent to which expression can be added is, of course, fairly limited on the Electron, but we can vary the individual volume of each note. This could be used for adding emphasis at the start of a bar or phrase, or for creating crescendo and diminuendo effects.



A Hupfield-Phonoliszt reproducing piano, dating from the turn of the century. The paper roll, which has both pitch and expression channels, can be seen above the centre of the keyboard (photo courtesy of The British Piano Museum Charity Trust, Brentford, Middlesex.)



Analogy between SOUND statement and a paper roll for a reproducing piano.
Pitch = channel (1 out of 88)
Duration = length of perforation
Loudness controlled by 'extra' expression channels

Certain alterations have to be made to the scale-playing program to enable the computer to play a recognisable tune from DATA statements, rather than just a scale. We must specify, individually for each note, both its pitch number and its duration. Note that a tune can also be stored in a DATA statement as a set of intervals, just as we did for scales. However, transposing a tune into a set of intervals is generally more difficult than transposing it into a set of pitch numbers. The intervals in a tune would of course be both positive and negative.

Later we will consider also specifying the loudness of each individual note. Thus each note in the tune must be specified as two or three data items representing:

(1) pitch number
(2) duration
(3) loudness

Selecting the pitch number and duration is just a matter of transposing the normal musical notation into numbers. Duration can be worked out using any convenient scheme such as:

Musical convention	Duration value (for metronome 150)
1/32 note (demi-semiquaver)	1
1/16 note (semiquaver)	2
dotted 1/16 (dotted semiquaver)	3
1/8 note (quaver)	4
dotted 1/8 (dotted quaver)	6
1/4 note (crotchet)	8
dotted 1/4 (dotted crotchet)	12
1/2 note (minim)	16
dotted 1/2 (dotted minim)	24
whole note (semibreve)	32

Note that there are notes that cannot be accurately represented at this tempo. For example, a dotted 1/32 note is 1.5 units in duration (only integers can be used as duration parameters in SOUND statements). Similarly a 1/16 triplet is 4/3 units per note, an 1/8 triplet 8/3 units per

note and a 1/4 triplet 16/3 units per note. Use of these phrases must be avoided or, if you are transposing composed music triplets must be altered. Alternatively, all the times could be multiplied by 3 and the music played at a slower tempo. In the table a crotchet is sustained for 8/20 second. Thus, using the above values for a piece of music would mean that the music was played at a rate of (20x60)/8 crotchets per minute - a metronome tempo of 150. These settings can be used for faster or slower music and they have the advantage that they are all integers. The duration parameter in the SOUND statement is multiplied by a constant that speeds up or slows down the above rate.

```
tempo = 2
    :
    :
SOUND 1, vol, note, tempo*standardvalue
```

or

```
tempo = 0.5  :REM only if there are no odd durations
    :
    :
SOUND 1, vol, note, tempo*standardvalue
```

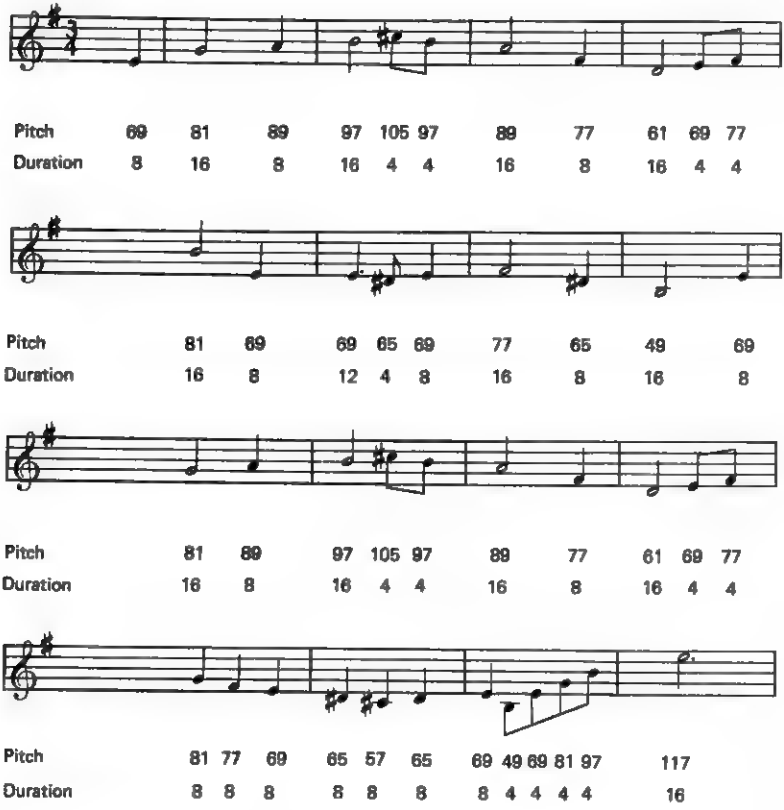
Here is a program that can be used to play a piece of music, given DATA statements containing pitch and duration codes for each note.

```
  5   INPUT tempo
 10   READ note, duration
 20   REPEAT
 30     SOUND 1, -10, note, tempo*duration
 40     SOUND 1,   0, 0, 0
 50     READ note, duration
 60   UNTIL note = -1

 70   DATA 69,8, 81,16, ...
        ... pitch and duration codes  ...
100   DATA -1,-1
```

Another point to note is that we have included a silent SOUND of zero duration between each note (line 40). The time taken by the sound generator to process this 'note' is sufficient to give the effect of an inter-note gap. In music sometimes notes are slurred together, sometimes not - it's a matter for experimentation. The use of the pitch ENVELOPE control (later) provides another way of creating the effect of a gap.

The pitch and duration values for the traditional ballad "Greensleeves" are now given, along with the music.

Greensleeves (Traditional)



More complicated rhythm and rests

Interesting music contains spaces or gaps of silence that have rhythmic significance. These are notated by rest marks.

In order to handle a piece of music that is transposed for rest marks and notes, we need a switch in the program that will enable notes or silence to be played for the appropriate time. To save having three DATA items per note we could use the highest pitch number to indicate that a rest is to be 'played'. Thus a rest appears in the DATA statement as a note of pitch number 255. This note is not now available and the rest is played at this pitch but with

zero loudness. Again using the metronome tempo 150, the durations for each rest mark are:

Musical convention	Duration (for metronome 150)
1/32 (demi-semiquaver) rest	1
1/16 (semiquaver) rest	2
1/8 (quaver) rest	4
1/4 (crotchet) rest	8
1/2 (minim) rest	16
whole (semibreve) rest	32

Here is the program to play music that includes rests:

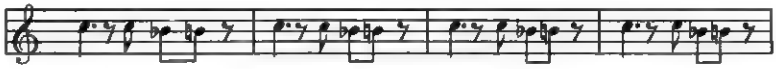
```
 10   firstime = TRUE
 20   INPUT tempo
 30   READ note, duration
 40   REPEAT
 50     IF note = 255 THEN loudness = 0
        ELSE               loudness = -10
 60     IF firstime AND note = 0 THEN
            RESTORE : firstime = FALSE
 70     SOUND 1, loudness, note, tempo*duration
 80     SOUND 1, 0, 0, 0
 90     READ note, duration
100   UNTIL note = -1

110   DATA 255, 4, 53, 4, ...
                :
                :
120   DATA 0, 0  :REM indicates repeat from start
                :
                :
200   DATA -1, -1
```

We have also included a structure that deals with a common situation in themes - repeating a sequence of bars. In the above theme the first four bars are to be repeated. This is accomplished by using an IF statement in conjunction with a RESTORE. We now need another data terminator at the end of the first four bars and have used the lowest pitch number - zero.

Here is a piece of music that includes rests and a repeat marker.

Tomboy (Steve Salfield)

Pitch 255 53 255 101 255 53 85 81 73 65 53 33 53 255 65 73 53
Duration 4 4 12 4 4 4 4 4 4 8 8 4 8 8 4 8 36

Pitch 101 93 85 81 81 255 81 73 77
Duration 4 4 8 80 8 4 4 4 12

Pitch 101 255 101 93 97 255
Duration 12 4 4 4 4 4

Exercises

1 Alter the "Greensleeves" program so that each note has three variable parameters and three items in the DATA statement. The third item is to be loudness. Try accenting the first note in each bar.

2 Write a program to change the pitch numbers in the DATA statement so that intervals are defined rather than pitch numbers. The key of "Greensleeves" is G major, so the first interval is 9 semitones or 36. All other intervals are then derived from the pitch numbers by subtracting the (n-1)th. from the nth.

1st interval	36
2nd interval	81-69
3rd interval	89-81
4th interval	97-89

The tune can then be played using the incremental technique used for scales, in any key. Use file facilities or an array to store the interval sequence.

10.5 Playing tunes from the keyboard

At this stage it is useful to introduce a program that will play notes from the keyboard and also change the characteristics of the note played as soon as an 'effect' key or 'organ stop' is pressed. You can then play tunes from the keyboard and instantly change the sound produced by pressing an 'effect' key, just as you would on an electronic organ. The structure of the program is amenable to any extensions that you wish to experiment with.

The program causes the keys on the bottom row of the keyboard to behave like the white notes on an organ or piano, with the keys on the row above behaving like black notes where appropriate. The key C represents Middle C. The schemes that you can set up are not limited to just playing notes. Keys can also be used to initiate effects as in an electronic organ. For example, a key could be used to select an ENVELOPE statement to control the SOUND statements (below).

First, here is the basic keying program that has to play a SOUND statement for as long as a key is depressed.

```
10   keys$ = "ZSXCFVGBNJMK,L./: "
20   *FX 11, 1
30   *FX 12, 1
40   currnote$=GET$
50   REPEAT
60     pitch = INSTR(keys$, currnote$)*4 + 37
70     SOUND 1,-15,pitch,255
80     REPEAT
90       note$ = INKEY$(2)
100    UNTIL note$<>currnote$
110    *FX 21,5
120    IF note$ = "" THEN currnote$ = GET$
                     ELSE currnote$ = note$
130  UNTIL currnote$ = " "
140  *FX 12,0
150  END
```

In the program the inner REPEAT loop causes the SOUND statement to be played UNTIL the key is no longer pressed or UNTIL a different key is pressed. The INKEY parameter defines the length of time that the program is to wait and see if a key is pressed. The value of this parameter has to be as small as possible (so that playing the keys fast is possible), but greater than the repeat rate at which characters are sent by a continually depressed key. The

repeat rate is decreased to its smallest possible value using a *FX call (see Appendix 10).

Handling effects

The above structure can easily be enhanced to include special effect keys. At this stage we introduce the use of the ENVELOPE statement which modifies the generated sound. An explanation of the ENVELOPE statement is postponed until later. For the moment all you need know is that an integer in the range 1-4 in the second (loudness) parameter in the SOUND statement refers to a predefined ENVELOPE statement. The 'effect' keys 1, 2, 3, 4 select one of four envelopes for playing subsequent notes and the P key (P for Plain) causes subsequent notes to be played without an envelope. The effect keys are checked by PROCcheckforstops, in between each note being played. A variety of stops could be examined by extending this procedure. The procedure also has to absorb the variable number of characters that will be sent by a stop key due to the increased key repeat rate.

```
 10  ENVELOPE 1,1,   1,-1, 1,1,2,1, 0,0,0,0,0,0
 20  ENVELOPE 2,1,   8,-8, 8,1,2,1, 0,0,0,0,0,0
 30  ENVELOPE 3,1,   1,-1,-1,4,8,4, 0,0,0,0,0,0
 40  ENVELOPE 4,1, -36, 4, 0,1,9,0, 0,0,0,0,0,0
 50  envelope = -15
 60  keys$ = "ZSXCFVGBNJMK,L./: "
 70  *FX 11, 1
 80  *FX 12, 1
 90  currnote$=GET$
100  REPEAT
110    PROCcheckforstops
120    pitch = INSTR(keys$, currnote$)*4 + 37
130    SOUND 1,envelope,pitch,255
140    REPEAT
150      note$ = INKEY$(2)
160    UNTIL note$<>currnote$
170    *FX 21,5
180    IF note$ = "" THEN currnote$ = GET$
                     ELSE currnote$ = note$
190  UNTIL currnote$ = " "
200  *FX 12,0
210  END

220  DEF PROCcheckforstops
230    IF INSTR(keys$, currnote$)>0 THEN ENDPROC
240    IF currnote$ = "P" THEN envelope = -15
250    IF INSTR("1234", currnote$) THEN
           envelope = ASC(currnote$)-ASC("0")
260    REPEAT: currnote$ = GET$
270    UNTIL INSTR(keys$, currnote$)
280  ENDPROC
```

10.6 Composing music with programs

There are many different ways in which a program can be made to generate music (perhaps 'generate' is a better word than 'compose' in the context of computer programs). One of the most common was used by Mozart when he invented a game that composed music using a pair of dice. The computer equivalent is to use a random number generator to generate musical patterns. The simplest scheme would involve the generation of a sequence of notes of random pitch and random duration but a melody generated by such a method might not be very interesting.

At the other end of the spectrum a melody generating program can be written to produce a particular musical style evocative of a certain musical genre or even a certain composer. Here considerable information is required by the program to categorise the style to be imitated. This may be in the form of probability distributions, not just first-order distributions (the probability that a certain note will occur), but second and higher-order distributions. A second-order probability distribution gives the probability that a certain note, x, will occur in a sequence, given that it is preceded by a note y. This makes the selection of a note dependent on the note(s) that have preceded it.

A general principle is that the more closely a program is required to approximate a style, the more information (probability distributions and other constraints) it needs about that style.

Because of their general importance, we shall first of all look at the technique of using first-order probability distributions.

Use of probability distributions in random selection

This technique is quite general and could be used in any context, computer poetry writing for example, where a random outcome is to be weighted according to a probability distribution. It's rather like a weighted dice. We do not want the dice to fall in such a way that there is a 1 in 6 chance of a particular face turning up. A weight inserted in the dice will influence its random behaviour and will cause one or more faces to be favoured. In a program the random number generator is the dice, and the weight is the probability distribution. For example, let us say that we want to generate a melody by selecting notes from the scale of C major, the probability of occurrence for each note being given in the next table.

These values might have been generated as a result of an analysis of a selection of music in the style in which we are interested.

Note	probability of occurrence
C (bottom)	13%
D	13%
E	15%
F	10%
G	16%
A	9%
B	12%
C (top)	12%

We now explain how to generate a note so that the probability of getting a particular note matches its entry in the above table. The basic technique used can be extended to deal with higher order probability distributions which are beyond the scope of this book.

We wish to generate a random number in the range 1 to 100 and select a note as follows:

Random number generated	Note chosen
1 - 13	C
14 - 26	D
27 - 41	E
42 - 51	F
52 - 67	G
68 - 76	A
77 - 88	B
89 - 100	C

We first set up an array containing the eight percentages. In order to select a note, we generate a random number in the range 1 to 100 and add up values from the array until the total is greater than or equal to the random number generated. The number of percentages added determine the note from the scale that is selected.

(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
13	13	15	10	16	9	12	12

```
rand=RND(100)
```

Say, for example, rand=43. Then the first 4 values in the frequency table are added before we obtain a total that exceeds 43. This means that we play the 4th note in the scale.

```
pitch=scalenote(4)
```

where the 8 pitch codes for our scale are held in an array 'scalenote'.

First-order probability distributions are not particularly useful in computer music generation or style synthesis - intervals are far more important than the absolute pitch of a note. That is, given that a particular note has occurred the interval to the next note is important. If you use probability distributions in music generation you must use second-order and above. The mathematics of second order probabilities is outside the scope of this text. First-order probabilities have been dealt with because of their general importance in different contexts requiring weighted random numbers (for example, in simulation programs or in deciding which move a program should make in a game). Try a music generating program using the above technique and see how inferior it is to easier ad hoc techniques now introduced.

A practical program to generate music in a particular style

We shall now proceed to develop a program, more on a pragmatic or ad hoc basis than on a mathematical basis. The program is the basic structure for a musical composition program and can easily be extended to incorporate more variety, etc., as suggested.

This program uses, as a musical vocabulary or note source, a jazz blues scale given as absolute pitch numbers on line 50. The program plays a 12 bar blues in this scale by:

(1) randomly selecting a starting note,

(2) randomly selecting a rhythm for a musical phrase, and,

(3) randomly selecting whether the phrase is to ascend or descend in major seconds.

```
 10   DIM blue(13)
 20   FOR note=1 TO 13
 30     READ blue(note)
 40   NEXT note
 50   DATA 45,57,65,69,73,85,93,105,113,117,121,133,141
 60   FOR bar=1 TO 12
 70     FORphrase=1 TO 2
 80       PROCselectstartnote
 90       PROCselectupdown
100       PROCselectphrase
110       PROCplayphrase
120     NEXT phrase
130   NEXT bar
140   END
```

```
150   DEF PROCselectstartnote
160     startnote = RND(13)
170   ENDPROC

180   DEF PROCselectphrase
190     sphrase=RND(5)
200     restoreto = 1000 +sphrase
210   RESTORE restoreto
220   ENDPROC

230   DEF PROCplayphrase
240     READ noofnotes
250     note = startnote
260     FOR i = 1 TO noofnotes
270       READ duration
280       SOUND 1,-10,blue(note),duration
290       note=note+ updown
300       IF note > 13 OR note < 1 THEN note=7
310     NEXT i
330   ENDPROC

340   DEF PROCselectupdown
350     IF RND(2) = 2 THEN updown= -1  ELSE updown=  1
360   ENDPROC

1001  DATA 8,2,2,2,2,2,2,2,2
1002  DATA 4,4,4,4,4
1003  DATA 2,8,8
1004  DATA 1,16
1005  DATA 4,2,6,2,6
```

The pitch numbers are stored in array 'blue'. The procedure that selects a start note is self-explanatory. Each phrase lasts for 1/2 note (duration = 16) and the procedure that selects the phrase selects a duration DATA statement by RESTOREing under control of a random number generator. (Note that using RESTORE with a variable name in this way will not work if the program is RENUMBERed.) PROCselectupdown controls whether the phrase is to ascend or descend and is self-explanatory. Line 300 arbitrarily sets the melody back to the 7th note in the scale if the generated sequence goes out of range.

Now this structure can easily be built upon by both constraining and extending the musical devices used; the extensions add variety and the constraints add realism. The suggestions are fairly arbitrary and you can make up your own devices and add effects as outlined in the next section.

Suggested extensions

(1) Extend rhythm phrases.

(2) Introduce rests in phrases.

(3) Allow intervals other than major seconds (i.e. allow 'note' to be incremented and decremented by an integer other than 1).

(4) Musically improve the 'out of range' recovery.

Suggested constraints

(1) Fast note phrases used consecutively should be followed by a long note.

(2) The final note should be the tonic (1st, 7th, or 13th) and should be a long note.

(3) A short note ascending passage should be followed by a descending passage or interval.

(4) Repetition of a phrase should be occasionally introduced.

(5) There are harmonic constraints given by the blues chord progression that can be used if you know the musical theory.

Eventually you should end up with a recognisably 'bluesy' sound that can then be elaborated with rhythm and effects covered in the next section.

10.7 The ENVELOPE statement

When a positive integer in the range 1 to 4 is used as a 'loudness' parameter in a SOUND statement, this means that variations in pitch of the sound will be controlled by an associated ENVELOPE statement. (We no longer have control over the loudness of the sound.) An ENVELOPE statement contains fourteen parameters. Only the first eight parameters are used on the Electron. The last six are ignored, but must be included. We will always set the last six parameters to zero.

```
ENVELOPE  n, t,
          pi1, pi2, pi3, pn1, pn2, pn3,
          0, 0, 0, 0, 0, 0
```

The first parameter, 'n', is the ENVELOPE number. This is the number referred to in the second parameter of a SOUND statement. Parameter 't' specifies the time increment or step (in 1/100ths of a second) that is subsequently employed by the other parameters. The next six parameters specify the shape of a 'pitch envelope' that permits controlled variation of the frequency of a sound during its duration. The frequency of the sound initially starts at the specified frequency (given by the pitch number) and then varies under control of the pitch envelope parameters. The sound waveform compresses (frequency increases) and expands (frequency decreases) in time and this is a form of 'frequency modulation'. The frequency of the sound waveform is controlled by the amplitude of another waveform - the pitch envelope.

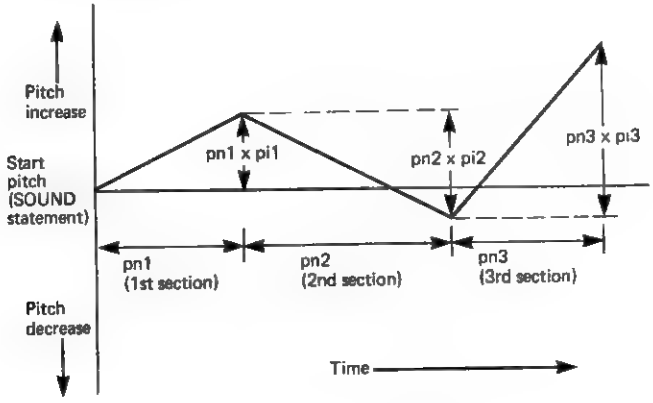
In music an instrumentalist may cause a slight pitch fluctuation around a particular note. The way in which this is achieved varies from instrument to instrument, but the technique is common with wind and string instruments. It is called vibrato and the pitch fluctuations are very slight. Much wilder pitch fluctuations are possible with the pitch envelope and it can be used to produce 'non-musical' effects.

The pitch envelope parameters control frequency variations over three sections:

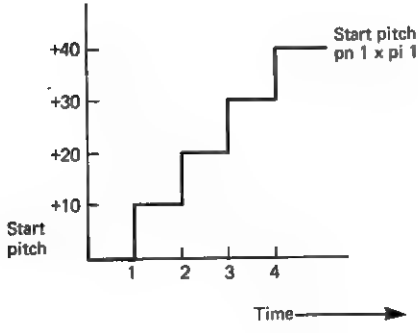
Parameter	Range	Effect
pi1	-128-127	change of pitch number per time step for Section 1
pi2	-128-127	ditto for Section 2
pi3	-128-127	ditto for Section 3
pn1	0-255	number of steps in Section 1
pn2	0-255	number of steps in Section 2
pn3	0-255	number of steps in Section 3

The effect of the pitch envelope lasts for t*(pn1+pn2+pn3) centiseconds and the envelope normally 'auto-repeats' if its duration is less than the duration parameter in the associated SOUND statement. The auto-repeat can be suppressed by setting the most significant bit of t to 1. Thus for a time step of 1 and auto-repeat suppressed t=129. A pair of parameters controls each section. For section 1, 'pi1' pairs with 'pn1', etc.

The following diagram illustrates the significance of the pitch envelope parameters.



General piecewise-linear form of a pitch envelope (t = 1). The straight lines are incremental steps
For example
pi1 = 10
pn1 = 4

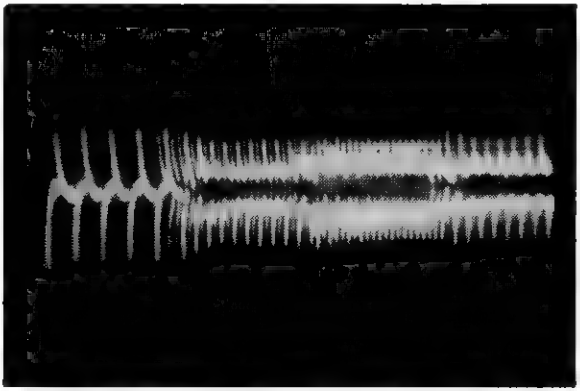


The next illustration is an oscilloscope photograph of a note under pitch envelope control. The parameters used were:

50, -50, 50, 1, 2, 1

and the starting pitch number 100. This results in pitches

100, 150, 100, 50, 100, 150, ...

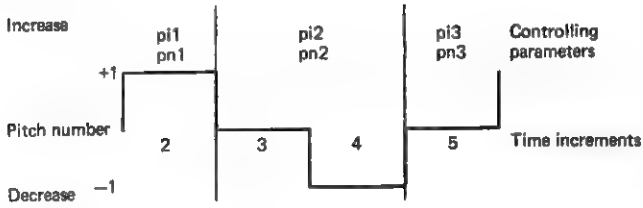


Oscilloscope photograph of a sound under pitch ENVELOPE control. Pitch ENVELOPE parameters: 50, −50, 50, 1, 2, 1 generating the pitch sequence 100, 150, 100, 50, 100, ...

Pitch variation in above photograph

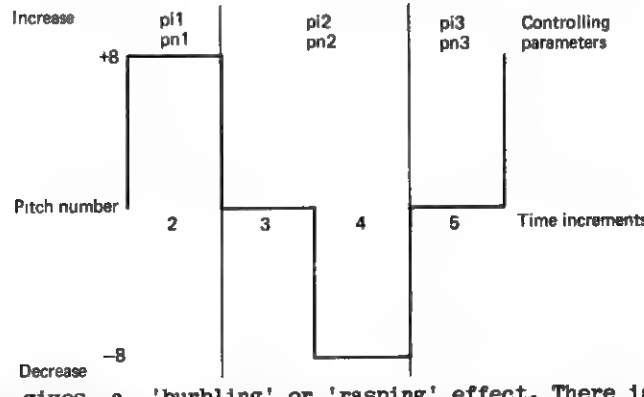
The following examples show some of the effects that can be achieved by methodically altering the pitch envelope. They also illustrate the relationship between the numbers and the envelope shape. As always for non-musical effects personal experimentation is best. The examples given can be tried with any envelope but the subjective effects described were obtained from an ENVELOPE with t=1. They are best tried out in conjunction with a tune from one of the earlier programs.

	1	2	3
pi	1	-1	1
pn	1	2	1



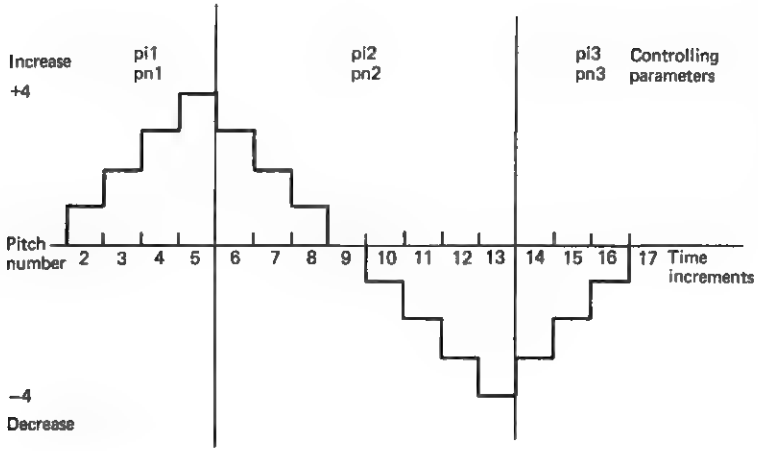
This gives a 'shimmering' effect. The pitch changes are minimal and there is a symmetrical sharpening and flattening of tone.

	1	2	3
pi	8	-8	8
pn	1	2	1



This gives a 'burbling' or 'rasping' effect. There is now excessive flattening and sharpening of the note, but this is not noticeable because it takes place very quickly compared with the 'electronic burbling'.

```
      1   2   3
pi    1  -1   1
pn    4   8   4
```



As you would expect the flattening and sharpening is now much more noticeable.

Wild variations of the parameters produce interesting effects.

```
      1   2   3
pi   50 -50  50
pn    2   4   2
```

In this example the effects are quite difficult to predict because the pitch decrement (4x -50) will attempt to reduce the pitch below zero. In this case positive pitch numbers are calculated using MOD 256 (see User Guide). If the effect of the pitch envelope is not to mask the tune, then the pn parameters must be short.

10.8 Special effects

There are many special sound-effects that can be created on the Electron and this something that you must experiment with yourself. Here are two examples of what can be done.

Glissandos

A glissando is a series of consecutive notes sounded very quickly. The most (ab)used musical glissando is produced by running a finger over the strings of a harp. In the next program, which produces an 'arcade game fanfare', a series of glissandos are played, each starting on a different note. The glissando effect is produced by using an appropriate pitch envelope.

```
10   ENVELOPE 1,1, 1,0,0, 50,0,0, 0,0,0,0,0,0
20   FOR start = 0 TO 80 STEP 4
30     SOUND 1, 1, start, 10
40   NEXT start
```

Channel 0

Channel 0 generates 'noise'; either periodic (bursts of noise) or white noise (noise containing many different frequencies - sounds like a waterfall). The particular noise selected is controlled by the value of the pitch number:

```
SOUND  0, loudness, p, duration
```

p	noise selected
0	High-frequency periodic
1	Medium-frequency periodic
2	Low-frequency periodic
4	High-frequency white noise
5	Medium-frequency white noise
6	Low-frequency white noise

Again experimentation with these effects is best left to you. Here is an example - the noise of machine gun-fire.

```
10   FOR bullet = 1 TO 50
20     SOUND 0, -15, 2, 1
30     SOUND 0, -15, 4, 1
40   NEXT bullet
```

Chapter 11 Animation

When film cartoons are made by hand, animated effects are created by drawing and photographing a large number of 'frames' which are then displayed by a projector at a speed that gives the impression of continuous movement.

Computer animation packages now exist that help the cartoon artist to create animated films. Such a package typically includes programs that help the artist to design scenes from the film, using commands for interactively drawing lines and colouring regions. An animation package also includes programs for carrying out tasks such as 'in-betweening', a tedious and time-consuming job carried out by the 'in-betweeners' or junior artists of the cartoon film industry. Here, the main frames of a film are created on the screen by an artist and the hundreds of in-between frames that bridge the gaps between the main frames are generated by the animation package, each frame being photographed as it is created.

If you have the facilities for making films and wish to use your Electron for creating cartoons, then the full power of the graphics facilities can be used in drawing each frame of the film. The time taken to change the image on the screen is not critical as each frame of the film will be photographed only when the changes on the screen are complete. It can take many hours of program runs to create a few seconds of film in this way.

The type of animation that is most likely to be of interest to the owner of the Electron is the creation of 'real-time' animation effects on the screen. These might be required as an essential element of a game or they might be created simply for entertainment. In such uses of animation, the speed at which the image on the screen changes is critical and this limits the range of programming techniques that can be used effectively. In this chapter, we shall be concentrating on real-time animation.

11.1 A simple moving object

It is important that the programmer who wishes to use real-time animation understands the limitations of the various techniques that can be used. There are two main methods of displaying information on the screen - we can use the various graphics plotting facilities or we can print

characters. Surprisingly, it is the latter facility that is more useful in creating effective animation. In this section, we shall look at the use of these two methods in programs that move a simple object across the screen. The object that we shall use is a very simple 'box-car' shape:

We shall make this shape 'drive' across the screen from left to right.

Using PLOT facilities for animation

The simplest idea that can be used to create animation effects is repeatedly to delete an object and redraw it in a different position. If this happens sufficiently quickly, then the object appears to move. A program to do this has the following outline structure:

```
Set x and y to initial position of object
Draw object at x,y

REPEAT
   Calculate newx, newy
   Delete object at x,y
   Draw object at newx,newy
   x = newx : y=newy
UNTIL final position reached
```

A good general principle that we have kept in mind while writing the above outline is that redrawing should occur as soon as possible after deletion.

One way of deleting an object is to redraw it in the current background colour and this is the method that is used in the rather unsatisfactory program below that implements the above approach.

The parameter of PROCcar that specifies the logical operation to be used in plotting is needed in the next section. Because speed of program execution is often critical in animation, we shall use integer variables (with '%' signs) throughout this chapter (see Appendix 8). It is important that you run this program for different values of 'xstep%' and observe the problems that it illustrates. The most obvious drawback is the flashing effect that is a result of the time taken to delete and redraw even this simple object. However, this defect can be eliminated by using the techniques of the next section.

```
 10   INPUT xstep%
 20   MODE 5
 30   cx% = 0 : cy% = 500 :REM initial car coordinates
 40   PROCcar(cx%, cy%, 0, 3)

 50   REPEAT
 60     nx% = cx% + xstep% :REM new x coordinate
 70     PROCcar(cx%,cy%,0,0)
 80     GCOL 0,3
 90     PROCcar(nx%,cy%,0,3)
                :REM y coordinate has not changed
100     cx% = nx%
110   UNTIL cx% > 1279

120   MODE 6 : END

310   DEF PROCcar(x%, y%, logop%, colour%)
320     GCOL logop%, colour%
330     MOVE x%,y%
335        REM all plots relative to previous point
340     PLOT 0, 64,0
350     PLOT 81, -64,64
360     PLOT 0, 64,0
370     PLOT 81, 0,-64
380     PLOT 0, 64,0
390     PLOT 81, -64,32
400     PLOT 0, 64,0
410     PLOT 81, 0,-32
420   ENDPROC
```

Image plane switching

The flashing effect exhibited by the above program was due to the fact that we could see the car being erased and redrawn. In order to eliminate this flashing effect, we need to arrange for the erasing and redrawing process to take place without it being seen. To do this, we need to work with two separate 'image planes' and display one plane on the screen while the erasing and redrawing process is being carried out in the other plane.

In MODE 5, the colour of each pixel is coded as a two-bit number. We saw in Chapter 9 that, instead of treating the screen as a single image plane in which each pixel is one of four colours, we can treat it as two separate image planes in which each pixel is one of two colours. In each MODE 5 pixel, one of the two bits is taken to represent the colour of a pixel in one plane and the other bit is taken to represent the colour of the corresponding pixel in the other plane. The alternative significance of each two-bit colour code is given by the following table:

Single image plane		Two separate image planes	
colour code	bit pattern	plane 1	plane 2
0	00	0	0
1	01	1	0
2	10	0	1
3	11	1	1

To switch between planes 1 and 2, we use VDU 19 statements to associate different combinations of actual colours with our four colour codes. For example, if we want 0 to be the background colour code and 1 to be the foreground colour code in each of planes 1 and 2, then we can selectively display one of the two planes by selecting one of the two actual colour combinations given in the following table:

Colour code	Actual colour settings	
	plane 1 displayed plane 2 hidden	plane 2 displayed plane 1 hidden
0	background	background
1	foreground	background
2	background	foreground
3	foreground	foreground

If we are using the same background and foreground colours in plane 1 as in plane 2, colour code 0 is always set to the background colour and colour code 3 is always set to the foreground. If the background colour is black and the foreground colour is white, then the colour codes 0 and 3 are correctly initialised in MODE 5. To switch plane 1 on and plane 2 off, we need only use:

```
VDU 19, 1,7, 0,0,0
VDU 19, 2,0, 0,0,0
```

and to switch plane 1 off and plane 2 on, we use

```
VDU 19, 1,0, 0,0,0
VDU 19, 2,7, 0,0,0
```

A new shape can be plotted in plane 1 by preceding the plotting instructions by

```
GCOL 1,1
```

A shape can be erased from plane 1 by replotting it after

```
GCOL 2,2
```

(see Chapter 9). Similarly, a shape can plotted in plane 2 by preceding the plotting instructions by

```
GCOL 1,2
```

and erased by redrawing the shape after

```
GCOL 2,1
```

The following is an outline of how we use the above technique to conceal the deleting and redrawing process while an object is being moved about the screen:

```
Set x,y to the initial position of the object
Switch plane 1 on, plane 2 off
Draw shape in plane 1

REPEAT
   Calculate newx,newy
   Draw shape at newx,newy in off plane
   Switch planes
   Erase shape at position x,y in plane that is now off
   x=newx : y=newy
UNTIL final position reached
```

In order to drive our box car across the screen until it is out of sight, the details are:

```
 10   INPUT xstep%
 20   MODE 5
 30   cx%=0 : cy%=500
 40   PROCswitchon(1)
 50   PROCcar(cx%, cy%, 1, on%)

 60   REPEAT
 70     newcx% = cx%+xstep%
 80     PROCcar(newcx%, cy%, 1, off%)
 90     PROCswitchon(off%)
100     PROCcar(cx%, cy%, 2, on%)
105               REM deletes car in off plane
110     cx% = newcx%
120   UNTIL cx% > 1279

130   MODE 6 : END

210   DEF PROCswitchon(plane%)
220     on% = plane% : off% = 3-on%
230     VDU 19, on%, 7, 0,0,0
240     VDU 19, off%,0, 0,0,0
250   ENDPROC

310   DEF PROCcar(x%, y%, logop%, colour%)
        ... as before
```

Now that we have eliminated the flashing effect, we turn our attention to the speed at which the car moves. The speed of motion can be varied by increasing the steps in which it moves. With xstep=64, the car takes just over 4 seconds to move across the screen. Taking bigger steps makes the motion rather 'jumpy'. This may seem a reasonable speed, but you should bear in mind that our program is doing nothing else but moving the car. If we were to use PLOT facilities to implement the animation for a game in which several objects such as spaceships were being moved about the screen and in which other calculations were taking place, then the rate of motion for each of the objects would deteriorate to an unacceptable level. In general, line plotting and colour filling facilities are too slow for most real-time animation. These facilities can, however, be used to good effect for creating backgrounds for character animation.

Using character printing to animate an object

In any of the graphics modes, a character shape can be displayed by a PRINT statement in considerably less time than it would take to draw the same shape using graphics commands. This is because of the fast techniques used to fill the area of the screen memory that is to be occupied by the character. We shall see later in the chapter how to define our own character shapes. In this section, we introduce the idea of using character printing to create moving objects. First, let us make a single character move horizontally across the screen as quickly as possible. The following program represents one way of doing this:

```
10   MODE 5
20   PRINT TAB(0,10); "*";
30   TIME = 0

40   FOR x%= 0 TO 18
50     PRINT TAB(x%,10); " *";
60   NEXT x%

70   PRINT TIME
```

Note that we have combined the process of deleting and reprinting the character in a single PRINT statement. The string printed consists of a space followed by a star. The space obliterates the old star at almost the same instant that the new one is printed. Care must be taken that printing does not take place beyond the end of the line or the star will appear at the beginning of the next line.

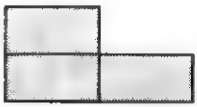
If you run this program, you will find that it takes only a few hundredths of a second for the star to cross the screen. If you want to see it, you will have to insert a delay loop between lines 40 and 50.

In applications where speed is a problem, for example if we are moving a large number of objects, there are often tricks that can be used to increase program speed. The above program can be speeded up slightly by using the backspace character instead of TAB:

```
10   MODE 5
20   s$ = CHR$(8)+" *"   :REM 8 is code for backspace.
30   PRINT TAB(0,10); "*";
40   TIME = 0

50   FOR x% = 0 TO 18
60     PRINT s$;
70   NEXT x%

80   PRINT TIME
```

The slight improvement in speed that this represents might be important in a complex program. As a rough rule of thumb, a TAB operation takes the same time as it does to print three or four backspaces. Note that in this case the semicolons at the end of lines 30 and 60 are essential.

Now let us return to our simple box-car shape. We can build this up in MODE 5 from characters, each of which is a solid block of colour:



We define such a character by using the VDU 23 command at line 15 in the program below. This sets the character whose code is 224 to be a solid block of colour. Details of how VDU 23 works are presented in a later section. Here is the program to move the car across the screen.

```
10   MODE 5
15   VDU 23, 224, &FF,&FF,&FF,&FF,&FF,&FF,&FF,&FF
20   blob$ = CHR$(240)
30   cara$ = blob$ : carb$ = blob$+blob$
40   PRINT TAB(0,10); cara$; TAB(0,11); carb$;
50   ca$ = " "+cara$ : cb$ = " "+carb$

60   FOR x%=0 TO 17
70     PRINT TAB(x%,10); ca$; TAB(x%,11); cb$;
80   NEXT x%
```

Although there are two characters in the bottom half of the car, only one leading space is needed in the string that deletes and reprints this part of the car - the image is being moved only one character position at a time. Because of the speed at which characters are printed, there is no appreciable flashing and the car moves across the screen in about one fifth of a second.

You will find the presence of the flashing text cursor annoying - it hovers round the object that is being moved. We can switch the cursor off or on by using the statements

```
VDU 23,1, 0;0;0;0;  to turn off the cursor
VDU 23,1, 1;0;0;0;  to turn on  the cursor
```

11.2 Diagonal motion - a bouncing ball

In the last section, the objects that we animated moved only horizontally. We can create vertical motion by changing only the y-coordinate of the object and diagonal motion can be obtained by changing both x and y coordinates together. To illustrate this we shall write a program that creates the effect of a ball moving diagonally on the screen and bouncing at the edges. The program will terminate if someone hits the space bar. The main part of the program will be:

```
10   MODE 4
20   PROCinitialise
30   PROCnewball

40   REPEAT
50     PROCmoveball
60     k$ = INKEY$(0)
70   UNTIL k$ = " "

80   MODE 6 : END
```

The INKEY$ function can be used if we want a program to look and see if a key has been pressed. The parameter in brackets indicates how long the program should wait if a key has not been pressed. The parameter 0 indicates that there should be no delay. If no key has been pressed, then the result of the function is the empty string, otherwise it is the character that has been typed. Thus our program will terminate and revert to MODE 6 if we hit the space bar.

PROCinitialise and PROCnewball are defined as:

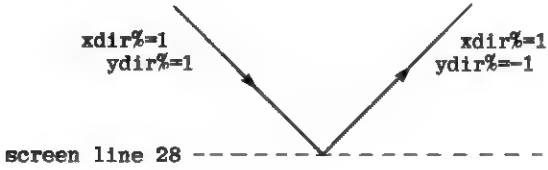
```
100   DEF PROCinitialise
110     VDU 23,1, 0;0;0;0;
120     ball$ = "o"
200   ENDPROC

210   DEF PROCnewball
220     bx%=RND(38) : by%=1 :REM ball coordinates
230     PRINT TAB(bx%,by%); ball$;
240     xdir%=1 : ydir%=1 :REM initial directions
300   ENDPROC
```

We have separated the initialisation process into two separate procedures for reasons concerned with later extensions of the program. The ball starts in a random position at the top of the screen. The variables 'xdir%' and 'ydir%', which are initialised to 1, represent the values that are to be added to 'bx%' and 'by%' each time the ball is moved. Thus the ball will start moving diagonally downwards towards the right.

Whenever the ball reaches one of the sides of the screen, the value of 'xdir%' must be changed and whenever it reaches the top or bottom of the screen, the value of 'ydir%' must be changed. For example, if xdir%=1, ydir%=1 and the ball reaches line 28 of the screen, then the statement:

```
ydir% = -1
```

should be obeyed so that the ball will subsequently be moved by adding 1 to its x-position and adding -1 to its y-position (until another direction change takes place).



PROCmoveball can be defined as:

```
310   DEF PROCmoveball
320     LOCAL nx%,ny% :REM new ball coordinates
330     IF bx%=1 THEN xdir%=1 ELSE IF bx%=38 THEN xdir%=-1
340     IF by%=1 THEN ydir%=1 ELSE IF by%=28 THEN ydir%=-1
350     nx% = bx% + xdir% : ny% = by% + ydir%
360     PRINT TAB(bx%,by%); " "; TAB(nx%,ny%); ball$;
370     bx% = nx% : by% = ny%
400   ENDPROC
```

We have left an unused margin round the edge of the screen for use in later extensions of the program. When doing character animation, it is advisable to leave an unused margin of at least one line along the bottom of the screen. This is because we must avoid, at all costs, the possibility of printing a character in the position at the bottom right-hand corner of the screen. Even if the PRINT statement were terminated by a semicolon, the computer would prepare to print the next character at the beginning of the next line and would 'scroll' up the whole screen to make room for it.

If you run the above program, you will find that the ball moves round the screen very quickly. There are two obvious ways in which it could be slowed down. We could insert a delay loop between lines 40 and 50, or we could simply increase the parameter of INKEY$ at line 60. We shall find that both of these methods are unsatisfactory when we introduce a bat into the program in the next section. A more satisfactory method of speed control will be discussed there.

11.3 Controlling movement from the keyboard: a bat'n'ball program

An essential requirement in video games is that the person playing the game should be able to control the movement of guns, bats, spaceships or 'snappers' from the keyboard. Let us illustrate this by extending the bouncing ball program so that a 'bat' moves in either direction across the bottom of the screen under the control of someone at the keyboard. We can extend PROCinitialise to position the bat centrally by including the following instructions.

```
130     btx% = 16 : bty% = 29 :REM bat coordinates
140     bat$ = "  ——  "
150     PRINT TAB(btx%,bty%); bat$;
```

The spaces at either end of 'bat$' are used to delete any part of the old bat that is left behind whenever it is moved one step to the left or to the right.

In order to increase the sensitivity of the keys that will control the movement of the bat, we insert commands in PROCinitialise to change the auto-repeat timings for the keys:

```
160     *FX 11,5
170     *FX 12,5
```

These commands were used in Chapter 10 and their effect is summarised in Appendix 10.

We prepare to recognise that the ball has gone out of 'court' by introducing a logical variable 'missed%' and initialising it in PROCnewball:

```
250     missed% = FALSE
```

The main part of the program is now amended to:

```
10   MODE 4
20   PROCinitialise
30   PROCnewball

40   REPEAT
50     PROCmovebat
60     PROCmoveball
70   UNTIL missed%

80   *FX 12,0
90   MODE 6 : END
```

The *FX command at line 80 resets the auto-repeat timings to their normal values.

PROCmovebat is defined as:

```
410   DEF PROCmovebat
420   LOCAL k$ :REM bat control key
430     k$ = INKEY$(0)
440     IF k$ = "Z" THEN btx% = btx%-1
          ELSE IF k$ = "X" THEN btx% = btx% + 1
          ELSE ENDPROC
450     IF btx%<0 THEN btx% = 0
          ELSE IF btx%>35 THEN btx% = 35
460     PRINT TAB(btx%,bty%); bat$;
500   ENDPROC
```

The keys used to control the motion of the bat are a matter of personal choice. Previously, when the ball reached the bottom of the screen, it bounced, but now we want it to bounce only if the bat is in position to hit it. Once PROCmoveball has calculated the new ball coordinates, it must check whether the ball is on the same row as the bat, and, if it is, it must check whether the bat is in position to hit the ball. We need:

```
340     IF by%=1 THEN ydir%=1
350     nx% = bx% + xdir% : ny% = by% + ydir%
355     IF ny% = bty% THEN PROCtryhit
```

where PROCtryhit is defined as:

```
510   DEF PROCtryhit
520     IF btx%<nx% AND btx% + 4 > nx%
          THEN ny% = bty%-1 : ydir% = -1 :
                                SOUND 1,-15,101,5
530   ENDPROC
```

IF the bat misses the ball, we leave 'ydir%' set to +1 and allow the ball to move on past the bat. We need to trap the ball before it goes off the bottom of the screen and this can be done by inserting the following line at the start of PROCmoveball:

```
328     IF by%=30 THEN
          PRINT TAB(bx%,by%);" "; : missed%=TRUE : ENDPROC
```

Now we consider the problem of slowing the ball down to a reasonable speed. The two obvious solutions mentioned earlier are rather unsatisfactory for different reasons.

If we change line 430 to:

```
430     k$ = INKEY$(10)
```

then as long as the bat is not being moved, there will be a delay of 10 hundredths of a second between each move of the ball. However, if we hold down one of the bat control keys in order to move the bat quickly, then the calls of INKEY$ will not have wait for values. This will have the effect of reducing the delay and speeding up the ball.

The other obvious way of slowing down the ball is to insert a delay loop somewhere in the main loop between lines 40 and 70. This would keep the speed of the ball constant, but it would slow down the program's response to the bat control keys which would be undesirable.

You should try both of the above methods for yourself and observe the effects described.

Timing animation events

We now describe a method for controlling the speed of one object in an animation program without creating unwanted side-effects on the motion of other objects in the same program. Each time an object is moved, the time at which the next move should take place is calculated and the object should not be moved again until TIME has passed this calculated value. For example, if we want a time delay of 10 hundredths of a second between each move of the ball, we introduce a variable 'btime%' whose value indicates the time at which the next move is to take place. We extend PROCinitialise to include:

```
125     bdelay% = 10 : btime% = bdelay%
126     TIME = 0
```

PROC moveball should now do nothing and exit immediately if it is not yet time to move the ball. When the ball is moved, 'btime%' should be reset to a new value. We require to insert these instructions at the start of the procedure:

```
322     IF TIME<btime% THEN ENDPROC
324     btime% = TIME + bdelay%
```

We are ensuring that the program will not activate an animation event until an appropriate time interval has elapsed since the last activation of the same event. Note that we can never guarantee that the time interval between events is exact. When this technique is being used, the variable TIME must not be altered by other parts of the program.

Exercises

1 Although the PLOT graphics statements are usually too slow for animation, they are very useful for drawing backgrounds. We have left a one-character margin round the top and sides of the 'court' in the bat'n'ball program. Use graphics commands to draw sides and a back for the court before the game starts.

2 Decide on a scoring system for the bat'n'ball program. For example, points could be scored each time the bat hits the ball, or the points scored could depend on the time that the ball is kept in play. An up-to-date score can be displayed and continuously reprinted on line 31 of the screen which has been kept clear for this purpose. NOTE: Any PRINT statement that displays information on line 31 must terminate with a semicolon, otherwise the whole court will scroll up each time the score is printed. As mentioned earlier, you must also avoid printing anything in the last character position on this line.

3 The section of our bat'n'ball program between lines 30 and 70 plays a game with one ball until it goes out of court. These lines could themselves be repeated:

```
25  REPEAT
        :
        :
75   ballsleft% = ballsleft%-1
76  UNTIL ballsleft%=0
```

with appropriate initialisation of 'ballsleft%'. Make this modification to the program and extend the display

on line 31 of the screen to include an up-to-date record of the number of balls left.

4 Allow the user to select different levels of play (with different speeds of ball) and set 'bdelay%' accordingly.

5 Add some further sound effects to the program.

11.4 A 'space-attacker' program

In this section, we present the outline of a very simple 'space-attacker' program. This program will demonstrate a combination of three different sorts of movement:

(a) A gun, controlled in exactly the same way as the bat in the previous section, will move backwards and forwards across the bottom of the screen.

(b) Characters representing enemy 'spaceships' will repeatedly appear at the top of the screen and will attempt to get past the gun at the bottom without being shot down. They will continuously take evading action and each spaceship will move faster than the previous one.

(c) When the gun is fired (by hitting the space bar), a bullet track or laser effect will be created by very rapid printing and erasing of a column of characters.

For the moment, an attacker will be represented by "*" and the gunsight by the letter "A". We shall see in the next section how to define more appropriate shapes for these characters.

The main part of the program is:

```
 10   MODE 4
 20   PROCinitialise

 30   REPEAT
 40     PROCmakeattack
 50   UNTIL lives%=0

 60   *FX 12,0
 70   MODE 6
 80   PRINT TAB(10,10); "GAME OVER"
 90   PRINT TAB(10,12); "SCORE: "; points%
100   END
```

PROCinitialise is defined as:

```
110   DEF PROCinitialise
120     *FX 11,5
130     *FX 12,5
140     VDU 23,1, 0;0;0;0;
150     gx% = 20 : gy% = 30
160     gun$ = "A"
170     PRINT TAB(gx%,gy%); gun$;
180     adelay% = 100 : TIME = 0
190     points% = 0 : lives% = 10
200     att$ = "*"
210     b$ = CHR$(11)+"¦"+CHR$(8):REM for bullet track
220     e$ = CHR$(11)+" "+CHR$(8):REM for track erase
230   ENDPROC
```

The use of 'b$' and 'e$' in creating the effect of a bullet track will be discussed shortly.

PROCmakeattack consists of a loop that is very similar to the main loop in our bat'n'ball program:

```
300   DEF PROCmakeattack
310     PROCnewattacker
320     REPEAT
330       PROCattacker
340       PROCgun
350     UNTIL attackover%
360   ENDPROC
```

Each time a new attacker is created, the speed will be increased. We do this by reducing the value of 'adelay%' by one tenth. Each new attacker starts at a random position on the top row of the screen:

```
400   DEF PROCnewattacker
410     ax% = RND(40)-1 : ay% = 0
420     PRINT TAB(ax%,ay%); att$;
430     adelay% = adelay% - adelay%/10
440     atime% = TIME + adelay%
450     attackover% = FALSE
460   ENDPROC
```

The procedure PROCattacker will be very similar in style to PROCmoveball in the last section. The main difference is in the way that the new attacker coordinates are calculated from the old ones. The attacker always moves down one step in the y-direction. However, we want it to take avoiding action as the player attempts to aim the gun at it. If the attacker is at the same x-position as the gun (line 560), then the program makes a random choice of whether it should

move left, right or stay in the same x-position. If the attacker is not on the same vertical line as the gun, then its x-coordinate is changed so as to move it away from the gun. The expression 'SGN(ax% - gx%)' has a value of +1 or -1 depending on which side of the gun the attacker is.

```
500   DEF PROCattacker
510   LOCAL nx%, ny% :REM new coordinates for attacker
520     IF TIME < atime% THEN ENDPROC
530     atime% = TIME + adelay%
540     IF ay% = gy% THEN
           lives% = lives%-1 : PRINT TAB(ax%,ay%); " "; :
           attackover% = TRUE : ENDPROC
550     ny% = ay% + 1
560     IF ax% = gx% THEN nx% = ax% + RND(3) - 2
                     ELSE nx% = ax% + SGN(ax% - gx%)
570     IF nx%<0 THEN nx%=0  ELSE  IF nx%>39 THEN nx%=39
580     PRINT TAB(ax%,ay%); " "; TAB(nx%,ny%); att$;
590     ax% = nx% : ay% = ny%
600   ENDPROC
```

The above procedure takes no account of the possibility of a collision between the attacker and the gun. We leave this aspect of the program as an exercise.

The procedure PROCgun will respond to the keys for controlling its movements in the same way as the bat control procedure of the last section. Since the gun consists only of a single character, it is convenient if the value of 'gx%' represents the horizontal position of the gun (and not the position of a preceding space as was the case with the bat). We also have one further command key to cater for:

```
610   DEF PROCgun
620   LOCAL k$, nx% :REM command key and new gun position
630     k$ = INKEY$(0)
640     IF k$=" " THEN PROCfire : ENDPROC
          ELSE IF k$ = "Z" THEN nx% = gx% - 1
          ELSE IF k$ = "X" THEN nx% = gx% + 1
          ELSE ENDPROC
650     IF nx%<0 THEN nx%=0 ELSE IF nx%>39 THEN nx%=39
660     PRINT TAB(gx%,gy%); " "; TAB(nx%,gy%); gun$;
670     gx% = nx%
680   ENDPROC
```

To create the effect of gunfire, the program will calculate the range of the shot and print a column of ":" characters from the gun either to the attacking spaceship or to the top of the screen. It will then erase these characters by printing spaces in exactly the same way. Because of the

speed at which this happens, there is no appreciable slowing down of the rest of the program.

```
710   DEF PROCfire
720   LOCAL r% :REM range of shot
730     IF gx%=ax% THEN r% = ay% : points% = points%+10 :
                        attackover% = TRUE
                    ELSE r% = 0
740     PROCtrack(r%, b$)
750     PROCtrack(r%, e$)
760   ENDPROC
800
810   DEF PROCtrack(r%, s$)
820   LOCAL y%
830     PRINT TAB(gx%, gy%);
840     FOR y% = 29 TO r% STEP - 1
850       PRINT s$;
860     NEXT y%
870   ENDPROC
```

Each character in our bullet track is printed by using a sequence of three characters. In the string b$, the character to be printed is preceded by CHR$(11) which moves the print position up one line and is followed by CHR$(8) which backspaces to the position of the character just printed. Starting off at the position of the character representing the gun means that the first character of the bullet track is printed immediately above the gun, the next immediately above that and so on. Carrying out the same process with string 'e$' overprints the bullet track with spaces. Of course the semicolon at the end of the PRINT statement on line 850 is vital.

Exercises

1 Introduce a more complicated scoring scheme into the attacker program. For example, the points scored could vary with distance from the gun. Display an up-to-date record of the progress of the game on line 31 of the display - points so far and number of attackers that have penetrated the defences.

2 No account is taken in our program of the possibility of the attacker colliding with the defender's gun. If this happens it should terminate the game. Modify PROCattacker so that it deals with such an occurrence.

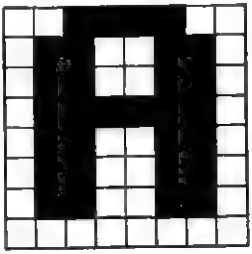
3 Add appropriate sound effects to the program.

11.5 User-defined characters

In modes 0, 1, 2, 4 and 5, the screen is divided up into a number of 'pixels' (see Chapter 9). For example, in MODE 4, there are 320x256 pixels.

In modes 3 and 6, the screen is divided into horizontal strips of pixels which are separated by strips of background colour. Each strip is 8 pixels deep.

In any of modes 0 to 6, printing a character has the effect of filling an 8x8 group of pixels with a pattern of foreground and background colour. For example, the pattern for "A" is:



Also associated with each character is an ASCII code number in the range 0 to 255. This code is used inside the computer to represent the character. The ASCII code for "A" is 65. When the character whose code number is 65 is to be displayed on the screen by a PRINT statement, the above pattern of foreground and background colour is inserted into the 'screen memory' that contains information about what is currently displayed on the screen.

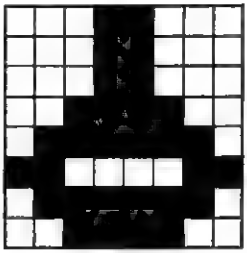
The user is normally free to define the character shapes that are associated with ASCII code numbers 224 to 255, and this is particularly useful when creating shapes for use in animation. In fact, it is possible for the user to define shapes for a much greater range of ASCII codes. (For details, consult the User Guide.)

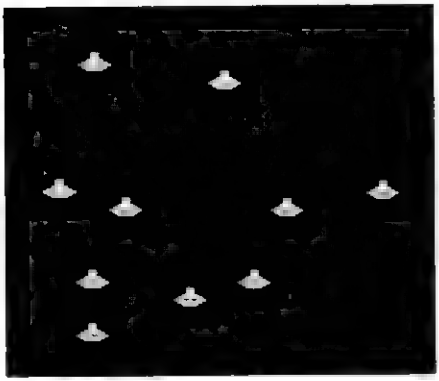
Once a new character shape has been defined, it can be displayed on the screen at the same speed as the predefined characters that we have used so far in this chapter.

The use of user-defined character shapes has two advantages over the use of PLOT instructions to draw shapes. Firstly, as we have already seen, a character shape is displayed on the screen at a much greater speed than can be achieved by using PLOT facilities. Secondly, the sequence of PLOT statements needed to draw a complex shape such as a spaceship would be rather lengthy.

Single character shapes

Let us demonstrate the process of defining a new character shape by defining a spaceship for use in the space-attacker program of the last section. The shape we shall define appears below together with a photograph showing several copies of the spaceship in MODE 5. Note that in MODE 5 (or MODE 2), a pixel (and therefore a character) is elongated.





Each row in the 8x8 pattern can be viewed as a byte (eight bits - see Appendix 5), and each byte can be written as an integer in the range 0 to 255. Thus the above pattern can be described as a list of 8 bytes or a list of 8 integers:

bytes	integers
00011000	24
00011000	24
00011000	24
00111100	60
01111110	126
11000011	195
01111110	126
00111100	60

A byte can also be written in the form of two hexadecimal digits. Four bits correspond to one hexadecimal digit as described in Appendix 5. Because of this correspondence, it is usually easier to write a pattern of 8 bits in hex than to convert it into an integer:

bytes	hex
00011000	&18
00011000	&18
00011000	&18
00111100	&3C
01111110	&7E
11000011	&C3
01111110	&7E
00111100	&3C

In order to define our new character shape, we must choose the ASCII code that we are going to use for the character and we must then calculate the sequence of 8 integers (in decimal or hex) that describes its shape. The ASCII code is associated with the required shape by using the VDU 23 command. For example, if we want ASCII character number 224 to appear on the screen as the above shape, we can use

```
10   VDU 23, 224, &18,&18,&18,&3C,&7E,&C3,&7E,&3C
```

We could equally describe the shape by writing the bytes in decimal:

```
10   VDU 23, 224, 24,24,24,60,126,195,126,60
```

We can display this spaceship in the centre of the screen in MODE 4 by:

```
20   MODE 4
30   PRINT TAB(20,10); CHR$(224)
```

We can use this spaceship in our space attacker program by making two simple changes to PROCinitialise. We must define our character and redefine 'att$':

```
195      VDU 23, 224, &18,&18,&18,&3C,&7E,&C3,&7E,&3C
200      att$ = CHR$(224)
```

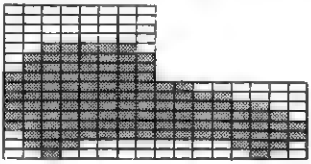
We could also define a new shape for the gun:

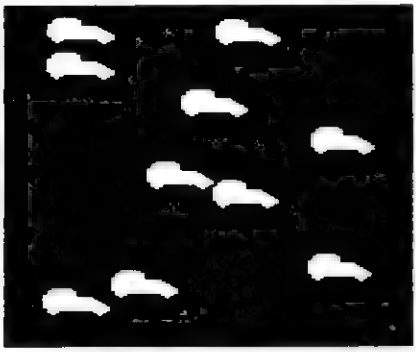
and include the definition of this shape in PROCinitialise by:

```
155     VDU 23, 225, &18,&18,&18,&18,&7E,&FF,&FF,&FF
160     gun$ = CHR$(225)
```

Composite character shapes

We can build up bigger objects by defining a number of different character shapes that can be printed together to make up the overall shape of the object. For example, we can slightly improve the shape of the car that was used in the program of Section 11.1 by defining three separate characters, one for the bonnet and front wheel, one for the body and back wheel and one for the roof:





The three characters required are defined by the bit patterns:

```
00000000   &0
00000000   &0
00000000   &0
00000000   &0
00111110   &3E
01111111   &7F
01111111   &7F
11111111   &FF

11111111   &FF          11000000   &C0
11111111   &FF          11110000   &F0
11111111   &FF          11111100   &FC
11111111   &FF          11111110   &FE
11111111   &FF          11111111   &FF
01111111   &7F          11111111   &FF
01110000   &70          00001110    &E
00100000   &20          00000100    &4
```

We can use these character shapes in the program at the end of Section 11.1:

```
  5   VDU 23, 224, &0; &0; &3E,&7F, &7F,&FF
  6   VDU 23, 225, &FF,&FF,&FF,&FF,&FF,&7F,&70,&20
  7   VDU 23, 226, &F0,&F8,&FC,&FE,&FF,&FF,&E,4
 30   cara$ = CHR$(224)
 31   carb$ = CHR$(225) + CHR$(226)
```

A character design program

Designing characters on paper is a tedious process and it is sometimes useful to have a computer program that assists us in the design process. We now present a complete listing of such a program.

The user of this program specifies the size of image he wants to construct (up to 4 characters across and up to 4 characters down). The program then displays a grid on the screen and the user can move a flashing cursor around this grid under the control of the four arrows that are normally used for screen editing. The normal behaviour of these keys is switched off by the line

```
  10   *FX 4,1
```

and back on again by the line

```
 220   *FX 4,0
```

The current point on the grid is switched to foreground colour by the key F and to background by the key B. At any time, the group of characters can be seen at its proper size in any of the modes 0 to 6 by pressing the corresponding numeric key. Typing V will display the VDU commands needed to define the characters. Typing S will save these VDU commands on a file and they can be later absorbed into a program using the *EXEC command (see Appendix 10). Typing R will retrieve a complete character image previously saved using the command S.

The program is terminated by typing "Q" (for Quit). If this is done in a state where the VDU commands are on the screen, these will remain on the screen and can be edited into a program by using cursor editing (as a quick alternative to *EXEC).

The structure of the program would have been improved if the various MODE commands had been tidied away inside the various procedures. However, a MODE statement cannot be obeyed inside a procedure.

```
 10   *FX 4,1
 20   MODE 1
 30   DIM pic(4,4,8)
 40   PROCinitialise

 50   REPEAT
 60     showing = FALSE
 70     IF redisplay THEN MODE 1 : PROCdisplay
        ELSE IF planning THEN PROCflash
 80     IF c$=up$    THEN PROCup
 90     IF c$=down$  THEN PROCdown
100     IF c$=right$ THEN PROCright
110     IF c$=left$  THEN PROCleft
120     IF c$="F" THEN foreground=TRUE
130     IF c$="B" THEN foreground=FALSE
140     IF c$="V" THEN MODE 6 : PROCvducodes
150     IF c$="S" THEN MODE 6 : PROCsave
160     IF c$="R" THEN MODE 6 : PROCrestore
170     IF c$="I" THEN MODE 1 : PROCinitialise
180     IF c$="H" THEN MODE 6 : PROChelp
190     IF c$="1" THEN PROCshowpic(1)
        ELSE IF "0"<=c$ AND c$<="6" THEN
               m=ASC(c$)-48 : MODE m : PROCshowpic(m)
200   UNTIL c$="Q"

210   IF planning OR showing THEN MODE 6
220   *FX 4,0
230   END
```

```
240   DEF PROCflash
250     LOCAL mask,pattern
260     PRINT TAB(col*8-bit,(row-1)*8+subrow-1);
270     mask=2^bit
280      IF foreground THEN
           pattern=pic(col,row,subrow) OR mask :
           currch$=on$
         ELSE pattern=pic(col,row,subrow) AND NOT mask :
           currch$=off$
290     pic(col,row,subrow)=pattern
300     REPEAT
310       PRINT on$;back$;
320       c$=INKEY$(10)
330       PRINT off$;back$;
340       IF c$="" THEN c$=INKEY$(10)
350     UNTIL c$<>""
360     PRINT currch$; back$;
370   ENDPROC

380   DEF PROCdisplay
390   LOCAL r,sr,c,b
400     VDU 23,1,0;0;0;0;
410     CLS : COLOUR 131
420     FOR r = 1 TO rows
430     FOR sr=1 TO 8
440       COLOUR 0
450       PRINT TAB(0,(r-1)*8+sr-1); startline$;
460       COLOUR 1
470       FOR c=1 TO cols
480       FOR b=7 TO 0 STEP-1
490         IF (2^b AND pic(c,r,sr))=0 THEN PRINT off$;
            ELSE PRINT on$;
500       NEXT:NEXT
510     NEXT:NEXT
520     planning=TRUE
530     redisplay=FALSE
540   ENDPROC

550   DEF PROCinitialise
560   LOCAL r,sr,c
570     PRINT:PRINT:PRINT
580     INPUT "Size of pic, cols",cols
590     INPUT "              rows",rows
600     IF cols>4 OR rows>4 THEN
          PRINT "SORRY, TOO BIG!" : END
610     VDU 23,254, &FE,&FE,&FE,&FE,&FE,&FE,&FE,0
620     on$=" " : off$=CHR$(254) : back$=CHR$(8)
630     up$=CHR$(139) :  down$=CHR$(138)
640     right$=CHR$(137):left$=CHR$(136)
650     VDU 23,255, &FE,&FE,&FE,&FE,&FE,&FE,&FE,&FE
660     startline$ = CHR$(255)
```

```
  670     FOR r=1 TO rows
  680     FOR sr=1 TO 8
  690     FOR c=1 TO cols
  700       pic(c,r,sr)=0
  710     NEXT:NEXT:NEXT
  720     col=1:bit=7:row=1:subrow=1
  730     foreground=FALSE
  740     nondispcodes$="023456VSRIH"
  750     PROCdisplay
  760     showing = FALSE
  770   ENDPROC

  780   DEF PROCup
  790     IF subrow<>1 THEN subrow=subrow-1
          ELSE IF row<>1 THEN row=row-1 : subrow=8
  800   ENDPROC

  810   DEF PROCdown
  820     IF subrow<>8 THEN subrow=subrow+1
          ELSE IF row<>rows THEN row=row+1 : subrow=1
  830   ENDPROC

  840   DEF PROCright
  850     IF bit<>0 THEN bit=bit-1
          ELSE IF col<>cols THEN col=col+1 : bit=7
  860   ENDPROC

  870   DEF PROCleft
  880     IF bit<>7 THEN bit=bit+1
          ELSE IF col<>1 THEN col=col-1 : bit=0
  890   ENDPROC

  900   DEF PROCshowpic(m)
  910   LOCAL r,c,sr,x,y
  920     planning = (m=1)
  930     showing = TRUE
  940     IF planning THEN
             x=8*cols+2 : y=3*rows : COLOUR 3 : COLOUR 128
          ELSE x=5 : y=5
  950     chno=223
  960     FOR r=1 TO rows
  970     FOR c=1 TO cols
  980       chno=chno+1
  990       VDU 23,chno
 1000       FOR sr=1 TO 8
 1010         VDU pic(c,r,sr)
 1020       NEXT sr
 1030     NEXT:NEXT
```

```
1040      chno=224
1050      FOR r=1 TO rows
1060        PRINT TAB(x,y+r);
1070        FOR c=1 TO cols
1080          VDU chno
1090          chno=chno+1
1100        NEXT c
1110        PRINT
1120      NEXT r
1130      PRINT:PRINT:PRINT
1140      IF planning THEN COLOUR 1 : COLOUR 131 : ENDPROC
1150      c$=GET$
1160      IF INSTR(nondispcodes$,c$)=0 THEN redisplay=TRUE
1170    ENDPROC

1180    DEF PROCvducodes
1190    LOCAL r,c,sr
1200      planning = FALSE
1210      CLS
1220      FOR r=1 TO rows
1230      PRINT "  Row "; r
1240      FOR c=1 TO cols
1250        PRINT "VDU 23,";
1260        FOR sr=1 TO 8
1270          PRINT ",&";~pic(c,r,sr);
1280        NEXT sr
1290        PRINT
1300      NEXT:NEXT
1310      c$=GET$
1320      IF INSTR(nondispcodes$,c$)=0 THEN redisplay=TRUE
1330    ENDPROC

1340    DEF PROCsave
1350    LOCAL r,c,sr,byte,channel,vdu$,fname$,code,lineno
1360      planning=FALSE
1370      PRINT:PRINT:PRINT
1380      INPUT "Filename",fname$
1390      INPUT "Character code",code
1400      INPUT "Program line number",lineno
1410      channel = OPENOUT(fname$)
1420      FOR r=1 TO rows
1430        FOR c=1 TO cols
1440          vdu$ = STR$(lineno)+" VDU 23,"+STR$(code)
1450          FOR sr = 1 TO 8
1460            byte=pic(c,r,sr)
1470            vdu$=vdu$ + ",&" + FNhex(byte DIV 16)
                                 + FNhex(byte MOD 16)
1480          NEXT sr
1490          PRINT vdu$
1500          PROCoutstring(channel,vdu$)
1510      code=code+1 : lineno=lineno+10
1520      NEXT:NEXT
```

```
1530    CLOSE# channel
1540    PRINT:PRINT "Characters saved on file"
1550    c$=GET$
1560    IF INSTR(nondispcodes$,c$)=0 THEN redisplay=TRUE
1570  ENDPROC

1580  DEF FNhex(d)
1590    IF d>9 THEN =CHR$(ASC("A")+d-10)
                ELSE =CHR$(ASC("0")+d)

1600  DEF PROCoutstring(c, s$)
1610  LOCAL i,l
1620    l = LEN(s$)
1630    FOR i = 1 TO l
1640      BPUT# c, ASC(MID$(s$,i,1))
1650    NEXT i
1660    BPUT# c,13
1670  ENDPROC

1680  DEF PROCrestore
1690  LOCAL r,c,sr,comma,char,byte,channel,fname$
1700    planning=FALSE
1710    PRINT:PRINT:PRINT
1720    INPUT "Filename",fname$
1730    PRINT:PRINT "Load tape and press PLAY"
1740    channel = OPENIN(fname$)
1750    FOR r=1 TO rows
1760      FOR c=1 TO cols
1770        FOR comma=1 TO 2
1780         REPEAT:char=BGET#channel
1790         UNTIL char=ASC(",")
1800        NEXT comma
1810        FOR sr = 1 TO 8
1820          char=BGET# channel
1830          char=BGET# channel
1840          byte=FNvalhex(char)*16
1850          char=BGET# channel
1860          byte=byte+FNvalhex(char)
1870          pic(c,r,sr)=byte
1880          char=BGET# channel
1890          PRINT ",&";~byte;
1900    NEXT:PRINT:NEXT:NEXT
1905    CLOSE# channel
1910    PRINT '"Characters restored."
1920    c$=GET$
1930    IF INSTR(nondispcodes$,c$)=0 THEN redisplay=TRUE
1940  ENDPROC

1950  DEF FNvalhex(d)
1960    IF d>ASC("9") THEN =d-ASC("A")+10
                      ELSE =d-ASC("0")
```

```
1970   DEF PROChelp
1980    planning = FALSE
1990    PRINT:PRINT:PRINT
2000    PRINT "Cursor arrows : Move around grid"
2010    PRINT "F             : Foreground"
2020    PRINT "B             : Background"
2030    PRINT "V             : Display VDU codes"
2040    PRINT "S             : Save on file"
2050    PRINT "R             : Restore from file"
2060    PRINT "I             : Initialise"
2070    PRINT "H             : Help"
2080    PRINT "0-6           : Display picture in mode"
2090    PRINT "Q             : Quit"
2100    PRINT "Any other key : Planning grid"
2110     PRINT:PRINT
2120     PRINT "After quitting, saved VDU statements"
2130     PRINT "can be absorbed into a program by:"
2140     PRINT:PRINT "  *EXEC ""filename"" "
2150     c$=GET$
2160     IF INSTR(nondispcodes$,c$)=0 THEN redisplay=TRUE
2170   ENDPROC
```

Exercises

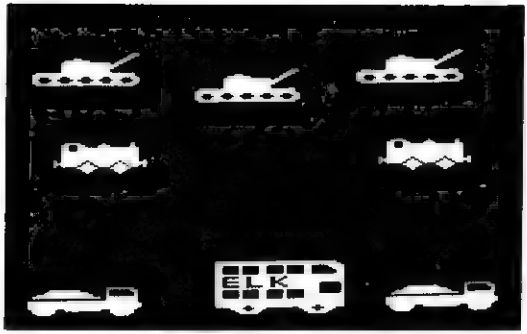
1 Define four different characters that represent the same spaceship in four different orientations. Incorporate these definitions in a program that moves the spaceship about the screen under the control of various keys that can be used to make it move forward, stop, turn right or turn left.

2 Design a block of four characters that represent a man with his arms outstretched and his legs apart. Define other characters that represent his arms and legs at different angles. Use your characters to display a 'flic-pic' by repeatedly displaying the man in the same place using randomly selected limb positions.

Note that if the characters 224, 225, 226 are the codes for three different versions of his top left-hand quarter, you can make a random selection of one of these characters and display it by, for example:

```
PRINT TAB(20,10);  CHR$(223+RND(3));
```

3 Design blocks of characters that represent different types of vehicles in a mode of your choice.



4 Design blocks of characters that represent different chess pieces.

5 Define a character that looks like an explosion and display this briefly when a spaceship is shot down, or when a spaceship collides with the gun. Make it flicker by overprinting it with a space and reprinting it several times.

6 In the 'bat'n'ball program, we used the underline character for constructing the bat. Because of this, there is a gap between the bat and the ball when they meet. Design and use a character for the bat that will eliminate this difficulty.

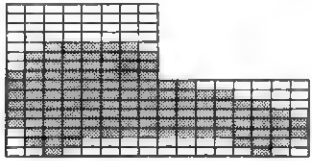
11.6 Multi-frame images - refining character animation

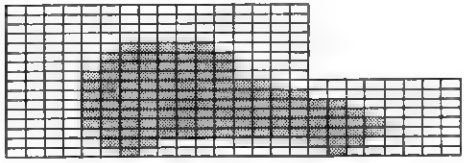
We saw in the last section how we could construct a picture from a group of user-defined characters that were displayed together on the screen. It is possible to create interesting effects by defining more than one version of the same object, each one slightly different from the others. In Exercise 2 at the end of the last section, we saw how this technique could be used to create a man waving his arms and legs.

By defining several versions or 'frames' for an object that is moving around the screen, we can improve the animation in two possible ways. First of all, the technique can be used to produce smoother motion by making the object move in steps of less than one character. Secondly, parts of the object can be made to move independently of the overall motion of the object, for example arms and legs can be made to swing.

Smoother movement

We first show how we can make our car move across the screen in steps that are smaller than one character position. We shall define two frames or versions of our car:





During the motion, these two frames will be displayed one after another in the same position, before stepping forward by one character position and displaying them again. First we define the string of characters that make up frame 1:

```
 10     REM frame 1. Characters for top half of car.
 20   VDU 23, 224, 0,0,0,0,3,7,7,&F
 30   VDU 23, 225, 0,0,0,0,&E0,&F0,&F0,&F0
 40     REM frame 1. Characters for bottom half of car.
 50   VDU 23, 226, &F,&F,&F,&F,&F,7,7,2
 60   VDU 23, 227, &FC,&FF,&FF,&FF,&FF,&FF,0,0
 70   VDU 23, 228, 0,0,&C0,&E0,&F0,&F0,&E0,&40

 80   bsp$ = CHR$(8)  :REM backspace
 90   dn$  = CHR$(10) :REM down line
100   up$  = CHR$(11) :REM up line

110   frame1$=CHR$(17) + CHR$(1) + CHR$(224) + CHR$(225)+
              bsp$ + bsp$ + dn$ + CHR$(17) + CHR$(2) +
              CHR$(226) + CHR$(227) + CHR$(228) +
              bsp$ + bsp$ + bsp$ + up$
```

CHR$(17) can be used to select a new colour for subsequent characters. Printing 'CHR$(17) + CHR$(1)' is equivalent to obeying the statement:

```
COLOUR 1
```

and printing 'CHR$(17) + CHR$(2)' is equivalent to obeying

```
COLOUR 2
```

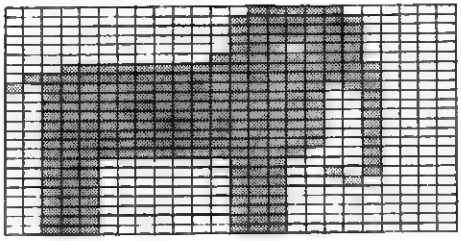
Thus, whenever 'frame1$' is printed (in MODE 5), the top half of the car is displayed in red and the bottom half in yellow. The combination of backspace, up-line and down-line characters has been chosen so that after printing frame1, the (invisible) text cursor is in position ready for printing frame 2. The program for moving the car across the screen can be completed with:

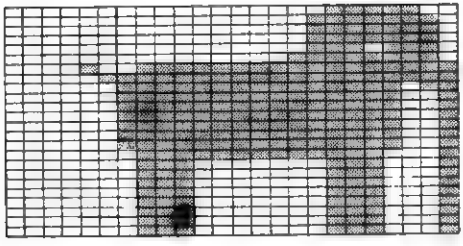
```
120     REM frame 2
130   VDU 23, 229, 0,0,0,0,&3E,&7F,&7F,&FF
140   VDU 23, 230, &FF,&FF,&FF,&FF,&FF,&7F,&70,&20
150   VDU 23, 231, &C0,&F0,&FC,&FE,&FF,&FF,&E,4
160   frame2$ = CHR$(17) + CHR$(1) + " " + CHR$(229) +
              bsp$ + bsp$ + dn$ + CHR$(17) + CHR$(2) +
        " " + CHR$(230) + CHR$(231) + bsp$ + bsp$ + up$

200   MODE 5 : VDU 23,1, 0;0;0;0;
210   PRINT TAB(0,10); frame2$;
220   FOR x%=1 TO 17
230     PRINT frame1$;
240     PRINT frame2$;
250   NEXT x%
260   K = GET : MODE 6 : END
```

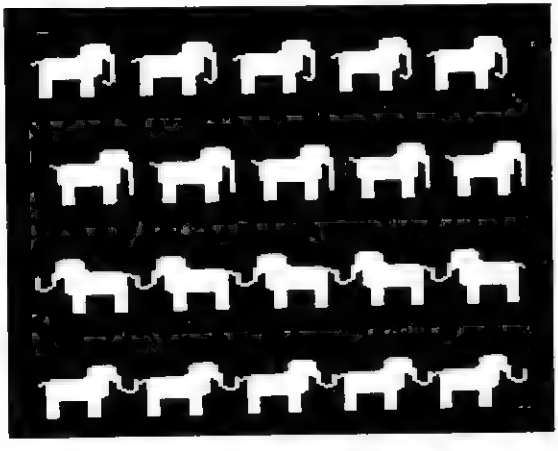
If you want to slow down the motion with a delay loop, remember that two delays will be necessary, one before printing frame 1 and one before printing frame 2.

Independent movement of parts

In the last section, the two image frames for the car differed only in the horizontal position of the car. We now show how slight changes in the shape of an object from frame to frame can be used to produce more effective animation. We shall illustrate this by animating an elephant that walks across the screen. We shall define only two frames for the elephant. Not only does the horizontal position of the elephant change from frame to frame, but the positions of the legs, trunk and tail relative to the rest of the body also change. The photograph shows, in the first two rows, several copies of each of the two frames in MODE 5. The next two rows in the photograph show two more variations on the same theme.







```
 5         REM frame 1
10    VDU 23, 224, 0,0,0,0,0,0,&1F,&7F
20    VDU 23, 225, 7,&F,&F,&F,&E,&1F,&FF,&FF
30    VDU 23, 226, &C0,&E0,&E0,&E0,&E0,&E0,&F0,&F0
40    VDU 23, 227, &BF,&3F,&3F,&3F,&3F,&3F,&3F,&3F
50    VDU 23, 228, &FF,&FF,&FF,&FF,&FF,&FF,&FF,&FF
60    VDU 23, 229, &B0,&90,&90,&90,&90,&90,&90,&10
70    VDU 23, 230, &38,&38,&38,&38,&38,&38,&38,&38
80    VDU 23, 231, &E,&E,&E,&E,&E,&F,&E,&E
90    VDU 23, 232, &10,&50,&20,0,0,0,0,0
```

```
100   bsp$ = CHR$(8) : dn$ = CHR$(10) : up$ = CHR$(11)
110   frame1$ = " " + CHR$(224) + CHR$(225) + CHR$(226) +
                bsp$ + bsp$ + bsp$ + bsp$ + dn$ +
                " " + CHR$(227) + CHR$(228) + CHR$(229) +
                bsp$ + bsp$ + bsp$ + bsp$ + dn$ +
                " " + CHR$(230) + CHR$(231) + CHR$(232) +
                bsp$ + bsp$ + bsp$ + up$ + up$

205         REM frame 2
210   VDU 23, 233, 0,0,0,0,0,0,9,7
220   VDU 23, 234, 0,0,0,0,0,1,&FF,&FF
230   VDU 23, 235, &7C,&FE,&FE,&FE,&EE,&FE,&FF,&FF
240   VDU 23, 236, 3,3,3,3,3,3,3,1
250   VDU 23, 237, &FF,&FF,&FF,&FF,&FF,&FF,&FF,&FF
260   VDU 23, 238, &FB,&F9,&F9,&F9,&F9,&F9,&F9,&F1
270   VDU 23, 239, 1,1,1,1,1,1,1,1,
280   VDU 23, 240, &C0,&C0,&C0,&C0,&C0,&C0,&C0,&C0
290   VDU 23, 241, &71,&71,&71,&71,&70,&70,&70,&70

310   frame2$ = CHR$(233) + CHR$(234) + CHR$(235) +
                bsp$ + bsp$ + bsp$ + dn$ +
                CHR$(236) + CHR$(237) + CHR$(238) +
                bsp$ + bsp$ + bsp$ + dn$ +
                CHR$(239) + CHR$(240) + CHR$(241) +
                bsp$ + bsp$ + bsp$ + up$ + up$
```

The loop for making the elephant walk across the screen is the same as that used for the car in the last section. The effect produced by the program is rather more interesting.

Exercises

1 Make the car move in smaller steps by defining four frames that represent the car in four different horizontal positions.

2 Define several different frames to represent a man in different walking positions and write a program that makes the man walk across the screen.

3 Use four different character shapes for the spaceship in four different orientations and make the spaceships spin as they move down in the space-attacker program.

4 Make our elephant walk across the screen and point with its trunk to one of several words displayed in a column at the right of the screen.

5 Because of the low resolution in MODE 5, our elephant has rather square corners. Use more characters to redesign the elephant in a mode with greater resolution, such as MODE 4, and animate it as before.

11.7 Special effects with palette changing

We have already seen in Chapter 9 that the actual colour displayed on the screen for a particular colour code can be selected from any one of the sixteen available colours. In MODE 4, only two colours (code numbers 0 and 1) can be displayed on the screen at any one time, but these two colours can be any two of the sixteen available. Thus the spaceship and gun in our space-attacker program can be displayed in yellow instead of white if PROCinitialise includes:

```
135     VDU 19, 1,3, 0,0,0
```

This says that the colour with code number 1 in MODE 4 should be displayed as actual colour number 3 (yellow). All objects printed on the screen during the game will now be displayed in yellow.

Obeying a VDU 19 statement like this does not involve replotting information on the screen and the colour change is effected instantaneously by the display hardware during the next raster scan of the screen (which takes about one fiftieth of a second). We have already made use of this instantaneous colour change in Section 11.1 where setting a colour code to black allowed us to draw an object in that colour without the drawing process being seen. By switching to a foreground colour, the drawn object can be made to appear instantaneously. In the following sections, we demonstrate how this palette changing facility can be used to create a number of special effects.

A gunflash effect

A VDU 19 command can be used to instantaneously change the background colour of the whole screen and this can be used to create a flash when a gun is fired, or for an explosion.

In the space-attacker program, we can change the background colour to red during the short period that it takes to draw and erase the bullet track. The background colour number is 0 and we need to insert a VDU 19 command to change the actual colour associated with code number 0 at the start of PROCfire:

```
725     VDU 19, 0,1, 0,0,0
```

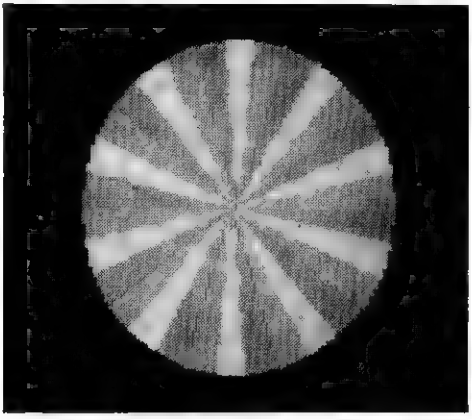
We need to reset colour number 0 to actual colour 0 (black) at the end of PROCfire:

```
755     VDU 19, 0,0, 0,0,0
```

A spinning disc

The next program draws a circular disc consisting of 30 different segments, where consecutive segments are plotted using colour codes 1,2,3,1,2,3, etc. In MODE 1, colour code number 2 is initially associated with actual colour 3 (yellow) and colour code number 3 is initially associated with actual colour 7 (white). The VDU 19 statements at the start of the program simply tidy this situation up by ensuring that colour code numbers 1,2,3 are associated with actual colours 1,2,3 (red, green, yellow).

```
 10   MODE 1
 20   VDU 19, 2,2, 0,0,0
 30   VDU 19, 3,3, 0,0,0
 40   VDU 29, 600;500;   :REM move graphics origin
 50   r = 300     :REM radius of disc
 60   segs = 30   :REM number of segments
 70   theta = 0 : thetainc = 2*PI/segs
                        :REM angle and increment
 80   MOVE r,0
 90   FOR seg = 1 TO segs
100     theta = theta + thetainc
110     x = r*COS(theta) : y = r*SIN(theta)
120     GCOL 0, seg MOD 3 + 1
130     MOVE 0,0 :REM establish triangle for colour fill
140     PLOT 85, x,y    :REM colour fill segment
150   NEXT seg
```



By repeatedly changing the actual colour of each segment to the actual colour of an adjacent segment, we can create the illusion that the disc is spinning. One way of doing this is to extend the program as follows:

```
310   displacement = 0
320   REPEAT
330     FOR code = 1 TO 3
340       actual = (code + displacement) MOD 3 + 1
350       VDU 19, code,actual, 0,0,0
360     NEXT code
370     displacement = (displacement+1) MOD 3
380   UNTIL INKEY$(0)=" "
390   MODE 6 : END
```

The loop from line 330 to line 360 changes the actual colours associated with codes 1,2,3 to the next sequence of values required. Tabulate values of the various arithmetic expressions involved in the above process to see how it works. The speed of rotation of the disc can be slowed down by increasing the parameter of INKEY$ at line 380.

Spiral patterns

Some interesting effects can be obtained by replacing the disc of the previous section by various spiral patterns and using palette changing to make these rotate. First of all, we draw a band of colour that spirals outwards from the centre of the screen.

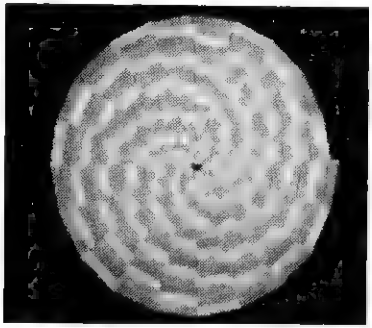
```
  10   MODE 1
  20   VDU 19, 2,2, 0,0,0
  30   VDU 19, 3,3, 0,0,0
  40   width = 20  :REM width of band of colour
  50   segs = 20   :REM coloured segments per rotation
  60   layers = 15 :REM complete rotations in spiral
  70   r = 0 :REM radius that increases as spiral is drawn
  80   theta = 0 :REM angle used to sweep out the spiral
  90   rinc = width/segs :REM radius increase per seg
 100   thetainc = 2*PI/segs :REM theta increase per seg
 110   VDU 29, 600;500; :REM move graphics origin
 120   x1 = 0 : y1 = 0 : x2 = width : y2 = 0
 130   MOVE x1,y1

 140   FOR step = 1 TO segs*layers
 150     GCOL 0, step MOD 3 + 1
 160     r = r + rinc : theta = theta + thetainc
 170     newx1 = r*COS(theta) : newy1 = r*SIN(theta)
 180     newx2 = (r + width)*COS(theta)
 190     newy2 = (r + width)*SIN(theta)
 200     MOVE x2,y2
 210     PLOT 85, newx2,newy2
 220     MOVE x1,y1
 230     PLOT 85, newx1,newy1
 240     x1 = newx1 : y1 = newy1
 250     x2 = newx2 : y2 = newy2
 260   NEXT step
```

Consecutive segments of the spiral are plotted in different colours. You should run the above program with different values for the variable 'segs'. If the number of segments is an exact multiple of the number of colours being used (3 in this case), then colours in adjacent layers of the spiral will match and the effect obtained is similar to that of the disc of the last section. If the number of segments is a whole number that is not a multiple of 3, then the colours in adjacent layers will not match and the spiral effect is more evident. The best effects are obtained by setting 'segs' to a non-integer value that is close to a multiple of the number of colours used. Try, for example,

```
50   segs = 20.5
```

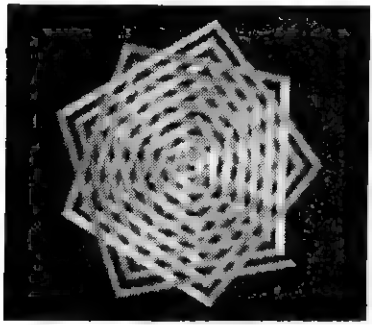
Interesting effects can also be obtained with small values of 'segs'. Try 3.5, 4, 4.5, 5, 5.5.

Now add lines 310 onwards from the rotating disc program to make the spiral rotate. The effectiveness of the illusion will depend on the value used for 'seg'. You can again vary the speed of rotation by adjusting the parameter of INKEY$.

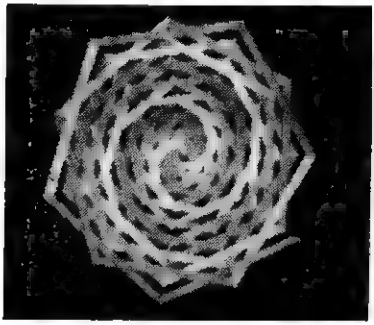


Segs = 20

Segs = 20.5



Segs = 4.5

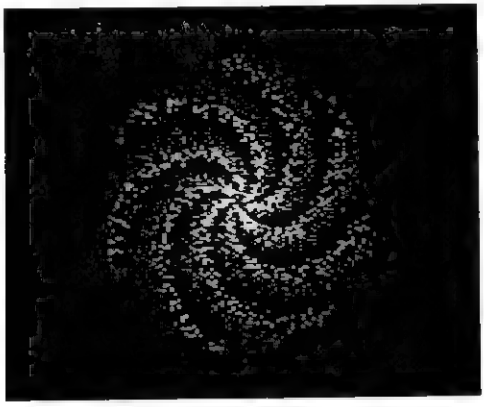


Segs = 5.5

We can obtain a catherine wheel effect by replacing each segment of solid colour by a collection of coloured spots. One way of doing this is to replace lines 160 to 250 by

```
160     FOR spot = 1 TO spots
170       rp = r + RND(1)*width
180       thetap = theta + RND(1)*thetainc
190       x = rp*COS(thetap)
200       y = rp*SIN(thetap)
210       PLOT 69, x, y
220     NEXT spot
230
240     r = r + rinc
250     theta = theta + thetainc
```

where 'spots' is initialised to a small value such as 10. Although the catherine wheel spins very quickly once it has been drawn, you will find that it takes several minutes to draw. The reason for this is that SIN and COS are very time-consuming functions. It is possible to generate a random set of points within a given segment without using SIN and COS, but we leave this as an exercise for those proficient in coordinate geometry. A better catherine wheel effect is obtained if one of the colours used in the palette-changing process is the background colour. This can be done by changing the calculation at line 340 or by using the technique suggested in Exercise 1 below. When we used black (background), red and yellow as our colours, the firework looked like this.



Exercises

1 At line 340 of the palette-changing process used in the last two sections, an actual colour (1, 2 or 3) was selected by calculation. By storing three actual colour numbers in locations 1, 2 and 3 of an array, and using the number calculated at line 340 as a subscript for this array, any combination of three colours from the sixteen available can be selected. Use this technique to experiment with different combinations of actual colours in the above programs.

2 Modify the palette-changing programs to run in MODE 2 with a bigger range of colours.

11.8 Joining the text and graphics cursors

One disadvantage of the character printing techniques that we have used so far for creating animation effects is that when a character shape is printed it completely obliterates anything that previously appeared on the screen in that area. None of the logical plotting operations that are selected by GCOL statements have any effect on the way that characters are normally displayed on the screen. This means that, when using normal printing techniques, we can not create the special effects such as foreground and background image planes that were illustrated in Chapter 9.

In this section we introduce the VDU 5 statement which causes characters to be displayed at the current graphics position. Issuing this command has a number of consequences:

(a) The colour for characters printed is selected by GCOL statements. This means that characters can be inserted on the screen under the control of the various logical operations on colour codes. We can create the effect of several image planes while still retaining the advantages of user-defined characters.

(b) A character can be displayed starting anywhere in the current graphics area by preceding the PRINT statement by a MOVE statement. The top left hand point of the character is displayed in the pixel at the current graphics position. This is useful for annotating graphs and charts. After printing a character, the graphics position is at the top left hand corner of the area where the next character would normally be printed. TAB has no effect on the position of PRINT output.

(c) Only the foreground part of the character is plotted. Printing a space on top of a previously displayed character no longer has the effect of erasing it. This

means that different shapes can be overlayed under the control of different GCOL statements and we are no longer limited to a single foreground colour within the area of a given character.

(d) When printing single characters, full windowing of the screen is effective. If a character is 'printed' off screen, it does not automatically appear elsewhere on the screen. Nor does any scrolling take place. However, if a string containing more than one character is printed at the edge of the screen, strange effects can take place.

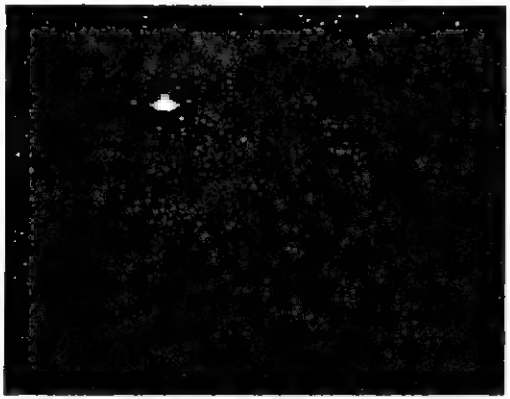
The price we pay for these advantages is loss of speed. It takes much longer to print a character after a VDU 5 statement has been obeyed. This is because of all the extra work that is being done behind the scenes in applying logical operations to colour codes and in making windowing calculations. You should therefore bear in mind that, despite the exciting possibilities, speed can be a problem when complex animation is involved. For example, when multi-character shapes such as the car or the elephant are being animated, printing takes place so slowly that the flashing effect observed in Section 11.1 returns and we would have to use the alternate image plane technique of section 11.1 for satisfactory results.

The next program introduces some of the effects that can be created by using the VDU 5 statement.

```
 10   MODE 5
 20   *FX 4,1
 30   *FX 11,5
 40   *FX 12,5
 50   VDU 5
 60   VDU 23, 224, &18,&18,&18,&3C,&7E,&C3,&7E,&3C
 70   VDU 23, 225, 0,0,0,0,0,&3C,0,0
 80   VDU 19, 2,3, 0,0,0
 90   VDU 19, 3,1, 0,0,0
100   ship$  = CHR$(18) + CHR$(3) + CHR$(1) + CHR$(224)
110   light$ = CHR$(18) + CHR$(3) + CHR$(2) + CHR$(225)

120   GCOL 0,2
130   FOR star = 1 TO 500
140     PLOT 69, RND(1279), RND(1023)
150   NEXT star

160   x% = 500 : y% = 500
170   step% = 64
180   PROCship(x%, y%)
```

```
190   REPEAT
200     k% = GET
210     ON k% - 135 GOTO 211, 212, 213, 214  ELSE  250
211       nx% = x% - step% : ny% = y% : GOTO 220
212       nx% = x% + step% : ny% = y% : GOTO 220
213       nx% = x% : ny% = y% - step% : GOTO 220
214       nx% = x% : ny% = y% + step% : GOTO 220
220     PROCship(x%, y%)
230     PROCship(nx%, ny%)
240     x% = nx% : y% = ny%
250   UNTIL k% = 32  : REM 32 is code for a space

260   *FX 4,0
270   *FX 12,0
280   MODE 6 : END

310   DEF PROCship(x%, y%)
320     MOVE x%, y%
330     PRINT ship$
340     MOVE x%,y%
350     PRINT light$
360   ENDPROC
```

We use the same 'spaceship' character as before, but this time we define a second character to fill the 'hole' in the spaceship with a different colour so that the hole now looks like a light. We also use the foreground-midground technique introduced in Chapter 9 so that our spaceship moves against a background of stars (single pixels lit up using PLOT 69). The stars are obscured when the spaceship passes over them. The movement of the spaceship is controlled by the user who moves it by pressing the four arrow keys.



Because of a shortage of colour codes in MODE 5, we have 'cheated' and the light on the spaceship is plotted in the same colour as the stars. This has an odd effect if the light passes over a star, but does not do much harm. The various possible colour codes at a pixel and their significance are:

Colour code	Bit pattern	Significance
0	00	(black) sky
1	01	(red) spaceship obscuring sky
2	10	(yellow) star or light
3	11	(red) spaceship obscuring star

Note that the character whose code is 18 can be used to create the effect of a GCOL statement. For example, printing the string

```
CHR$(18) + CHR$(3) + CHR$(1)
```

has exactly the same effect as the statement

```
GCOL 3, 1
```

Finally, note that the VDU 5 effect is switched off by VDU 4.

Exercises

1 Interesting effects can be obtained when the spaceship passes over stars if colour code 3 is set to one of the flashing colours. Try this.

2 Modify the space attacker program to use the VDU 5 statement. There are a number of alterations that will need to be made. MOVE will have to be used in place of TAB - it may be more convenient to express positions in graphics coordinates. You will need to issue the instruction

```
GCOL 3,1
```

in PROCinitialise and replace all the spaces previously used to erase characters by copies of the characters themselves. After these alterations have been made, you will find that the last character of the bullet trace no longer erases a spaceship that has been shot down and this will have to be dealt with. Firing a bullet will now be a much slower process and a faster alternative would be to draw and immediately erase (by drawing again) a dotted line running up the screen from the gun.

3 Now try plotting a background of stars for the space

attacker program. Although we are working in MODE 4 with only two colours available, you should find that a spaceship can pass over the stars without erasing them. (Actually, a hole appears momentarily in the spaceship as it passes over a star.) This is because all our plotting and erasing is being done using the exclusive or option. You could also change the program to run in MODE 1, but this will slow it down.

4 Modify the car programs written earlier to run with the VDU 5 option. Observe the problems that arise and try to cure them. Try making the wheels a different colour from the body by overlaying different characters in different colours.

Appendix 1 Typing and editing programs

The keyboard - general

Most of the keys on the keyboard, when pressed, cause characters to appear on the screen. These are the letter keys, each of which is marked on top with a letter of the alphabet, and the symbol keys, each of which is marked on top with symbols. In addition, there are a number of keys that are used for special purposes.

The letter keys

When the Electron is first switched on, the light to the left of the keyboard is lit. This means that 'CAPS LOCK' is on. In this state, pressing a letter key types a capital letter. To type a small letter, you must hold down SHIFT and press the letter key.

By holding down SHIFT and pressing CAPS LK, you can switch CAPS LOCK off or on.

With CAPS LOCK off, pressing a letter key types a small letter and to type a capital letter, you must hold SHIFT down.

If you adopt the typing style used for programs in this book, you will find it most convenient to switch CAPS LOCK off while typing programs (holding down SHIFT when necessary). If a program expects capital letters as input, it may be more convenient to switch CAPS LOCK on when running the program.

The two-character symbol keys

The keys that are marked on top with two symbols, such as numeric digits or punctuation marks, behave as they do on a normal typewriter. Their behaviour is unaffected by CAPS LOCK. Simply press the key to type the lower symbol; hold down SHIFT and press the key to type the other symbol.

The cursor arrows and the COPY key

These five keys are at the top right of the keyboard. The normal use of these keys is in editing programs - see below. The two symbols marked at the rear of these keys can be typed. To type the left-hand symbol, hold down SHIFT and press the key; to type the right-hand symbol, hold down CTRL ('control') and press the key.

BASIC keyword keys

Many of the keys described above also have Electron BASIC keywords marked on the front of the key. If a keyword appears on the front of a key, then you need not type that word in full. You can type the complete word by holding down FUNC ('function') and pressing the keyword key. (The keys for RUN and OLD include the effect of pressing RETURN.) Other keywords must be typed in full in capital letters.

The RETURN key

The computer will not pay attention to anything you type until you press the RETURN key. This key must be pressed after each command line and after each numbered BASIC line.

The DELETE key

Before pressing RETURN, you can edit the line currently being typed by using the DELETE key to delete characters.

The ESCAPE key

This is used to tell the computer to interrupt whatever it is doing and await new instructions. It does not delete your current program.

The BREAK key

This has an effect similar to, but more drastic than, the ESCAPE key. It switches the machine to MODE 6 (clearing the screen) and wipes out the current program (although this can be restored using the OLD command).

The user-defined function keys, f0 to f9

To type one of the function keys, hold down FUNC and press the key. The effect of these keys can be defined by using the *KEY command. This command is followed by the number of the key that you want to define and a string that contains the commands that are to be obeyed when the key is pressed. For example

*KEY 0, "DATA"	Every time f0 is pressed, it behaves as if the word DATA had been typed.
*KEY 9, "MODE 6:LIST |M"	Every time f9 is pressed, the machine will switch to MODE 6 and the current program will be listed. The |M (vertical bar followed by M) is used in the string in place of RETURN.

In fact the effect of other keys can be defined in this way. BREAK is f10 and the command *FX 4,2 will permit COPY and the cursor arrows to be redefined as f11 to f15.

Program line numbering

Lines are usually numbered in steps of 10. This makes it possible to insert new lines between the existing lines of a program by giving the new lines numbers that fall between the existing line numbers.

In the text, we have often left larger gaps in the numbering, for example we have sometimes started numbering each procedure with a different multiple of 100. This makes it easier to present later extensions to programs where the new lines are still numbered in steps of 10.

If necessary, the lines of a program can be renumbered by using the command RENUMBER. When used on its own, this command renumbers the lines of the current program starting with line 10 and going up in steps of 10. If RENUMBER is followed by a single parameter, that parameter specifies the number to be used for the first line of the program and the remaining lines are numbered in steps of 10. If RENUMBER is followed by two parameters, then the first parameter specifies the number for the first line of the program and the remaining line numbers go up in steps that are specified by the second parameter. For example:

```
RENUMBER 500      Lines are numbered 500, 510, 520, 530, ...

RENUMBER 200,5    Lines are numbered 200, 205, 210, 215, ...
```

Listing programs

A complete program can be listed on the screen by using the LIST command. If a program is too long to fit on the screen, then part of the program can be listed by giving line numbers in the LIST command, for example:

```
LIST 360          List line 360 only.

LIST 400,550      List lines from 400 to 550 inclusive.

LIST 460,         List lines from 460 to the end.

LIST ,200         List lines up to line 200.
```

Deleting lines

To delete a single line from a program, type the line number followed immediately by RETURN. To delete several lines from a program, use the DELETE command, for example:

```
DELETE 320,460        Deletes lines 320 to 460 inclusive.
```

Blank lines

It improves the readability of a program if blank lines are occasionally inserted between different program sections that carry out logically separate tasks. There are two ways of doing this. A blank line can be forced after a given line by typing extra spaces at the end of the line so that the line overflows onto the next screen line. Alternatively, blank lines can be numbered, but the number must be followed by at least one space.

Long lines

A single numbered line in a BASIC program can occupy up to 240 characters, or six screen lines in MODE 6. When a long line is being typed, you must not press RETURN until the complete BASIC line has been typed. The BASIC line will automatically overflow onto the next screen line when necessary.

Spaces and indentation

If speed of program execution is not critical (it rarely is) and program storage space is not in short supply, then extensive use of extra spaces typed in a program can help to make it much easier to read. At least one space should be inserted after each line number and spaces should be used to separate BASIC keywords from variable names. Sections of program can be made to stand out by 'indenting' them (typing one or two extra spaces at the start of each line) and this should be done between FOR and NEXT, between REPEAT and UNTIL, and in the definitions of procedures and functions. The layout of a long line can often be improved by forcing overflow onto the next screen line at a sensible point by typing extra spaces.

Omitting such redundant spaces makes a minute difference to the speed of execution of a program, and in the rare cases where speed of execution is critical, these redundant spaces can be omitted.

Extra spaces also take up memory space, and they may occasionally have to be omitted in order to fit a very large program into the computer.

If extra spaces have to be omitted, the LISTO (LIST Option) command can be used to slightly improve the layout of programs when listed. For example,

```
LISTO 7
```

Says that an extra space should be inserted after each line number and FOR and REPEAT loops should be indented by two

extra spaces whenever a program is LISTed. This command will not do anything to improve the layout of multi-line statements.

Cursor editing

The flashing 'cursor', in the shape of an underline character, normally indicates where on the screen the next character typed from the keyboard (or printed by the computer) will appear. The four arrow keys at the top right-hand corner of the keyboard can be used to change a line of program without having to retype it. Pressing one of the arrows immediately creates two cursors: the white block marks the point on the screen where the next character of the new line being typed will appear. The flashing underline symbol is the 'editing cursor' or 'copy cursor'. This cursor can be moved about the screen by using the arrows and any character currently marked by the copy cursor can be copied into the new line by pressing the COPY key. The computer is said to be in 'edit mode'.

Editing a line of program

To edit a line of the current program, you must first LIST it on the screen, then use the arrows to move the copy cursor to the start of the displayed line that is to be changed. Now use the COPY key to copy the parts of the old line that are correct, and type any additions or corrections from the keyboard. The arrow keys can be used to skip parts of the old line that are to be omitted, or even to move to another line and include part of that in the new line being constructed. Mistakes in the new line can be corrected with the DELETE key in the normal way and when the new line is complete, the RETURN key should be pressed.

Appendix 2 **Cassette files**

Saving programs on file

A BASIC program can be saved on cassette by using the SAVE command, for example

```
SAVE "progname"
```

where the program name can have up to ten characters. The computer will tell you to press RECORD on the tape recorder and then press RETURN. (The tape recorder must, of course, be connected to the socket marked 'cassette' at the side of the computer.) The program is recorded on the cassette in the form of a 'file'. The file consists of a sequence of 'blocks' on which audio signals representing the program are recorded. As the program is being recorded, these blocks are counted (in hex) on the screen. In the gaps between the blocks, a pure audio tone is recorded. You can hear what the program 'sounds' like by playing back the tape. Incidentally, a program does not have to be complete before it is saved. You can save a large program when you are half way through typing it.

Loading programs from file

In order to reload a previously saved program into the computer, use the command

```
LOAD "progname"
```

and press PLAY on the tape recorder. The blocks will again be counted on the screen as they are read by the computer. If the method used to connect your tape recorder to the computer does not automatically switch off the loudspeaker on the tape recorder, then you will find the noise made by the recorded programs disturbing. You have to insert a blank plug into the earphone socket in order to switch off the loudspeaker. (Do not use the short-circuit plug that is sometimes provided for insertion in the microphone socket when erasing tapes.)

You will have to experiment with the volume control on the tape recorder to find the best setting for reloading programs. The tone control should be adjusted to its highest setting. If the computer misreads one of the blocks, it will ask you to rewind the tape. (You do not need to rewind to the start of the program, only to the block that was misread.)

You may have problems loading a program that was saved with a different tape recorder. This can be caused by slight differences in tape head alignment or by differing characteristics of the record and playback circuits.

Cataloguing the programs on a tape

The *CAT command can be used to obtain a list of the names of the programs that are stored on a tape. Type this command and then play the tape. When you have obtained the information that you want, press ESCAPE.

If you save a long program that you have just typed, it is a good idea to rewind the tape and do a *CAT to make sure that the program has been recorded correctly before switching off the computer and losing the program.

Merging two programs

You may occasionally want to combine two BASIC programs into one. For example, you may have a collection of procedures developed in one program that you want to add to another program so that they can be called by the other program. You must first load one of the programs (usually the shorter) and renumber the lines so that they are different from the line numbers in the other program. For example,

```
RENUMBER 2000
```

will renumber the lines of a program from 2000 upwards. The renumbered program should now be saved on cassette in character form. This can be done by using the *SPOOL command, for example,

```
*SPOOL "ONEPROG"
```

After this command has been issued, everything that appears on the screen is also output in character form to the file "ONEPROG". To store our program on cassette in character form, we need only type

```
LIST
```

The characters listed on the screen will also be sent to the file. If only part of the program is to be merged with the other one, then only selected lines need be listed. Output to the file is then terminated by the command

```
*SPOOL
```

with no file name. If you do not have the remote control switch on your tape recorder connected, the computer will be unable to switch off the tape recorder automatically and there will longer gaps than usual between blocks. However,

this does not matter.

The other program must now be loaded in the usual way and the program that was saved in character form can now be added to the first by issuing the command

```
*EXEC "ONEPROG"
```

This tells the computer to read characters from the file "ONEPROG" and 'pretend' that they are being typed at the keyboard. This will have the effect of adding the previously renumbered program to the one that is currently in store.

Storing data on cassette files

There are many circumstances in which it is convenient to store information, such as numbers or strings, on files. If several programs require to process the same values, these values can be stored on a file and input from the file to each program as required. If a program is required to use the same large quantity of data each time it is run, there may not be room in store for these values to be held in DATA statements, and the solution would again be to create a file containing the values required by the program. Another possibility is that output sent to a file by one program can be supplied as input to a second program for further processing. A final important possibility is that a collection of data about some topic (a 'database') may be built up over a period by several runs of a program. The information could be held on a file between runs of the program. Each time it was run, the first thing the program would do would be to input the file containing the latest state of the database, and the last thing it would do would be to output the new state of the database to a new file. Perhaps we should mention that in most realistic database applications, the database is so large that it will not fit in the computer's main memory, and the files containing the database (usually disc files) are organised in such a way that part of the database can be input from file, updated, and output to file, as required.

Creating a file of numbers

To create a file, a program must do three things. It must tell the computer that it is about to create a file (i.e. it must 'open' the file by using the OPENOUT function). It must then send information to the file, in much the same way as information is sent to the screen, by using a variation of the PRINT statement called PRINT# (or by using BPUT# which is not covered here). Finally, the computer must be told that no more information is going to be sent to the file - the file must be 'closed' using the CLOSE# statement. For example, the following program allows the user to input a specified number of values (experimental readings, say) and

saves these values on a file.

```
10   fileno = OPENOUT("readings")
20   INPUT "How many readings", n
30   PRINT# fileno, n
40   FOR i=1 TO n
50     INPUT nextreading
60     PRINT# fileno, nextreading
70   NEXT i
80   CLOSE# fileno
```

Note that OPENOUT creates a file number which must be used subsequently by the program when using PRINT# to send information to the file and later when using CLOSE# to close the file. The only point at which the name of the file is mentioned is in the OPENOUT function.

The program could let the user choose his own name for the file of readings as follows:

```
 5   INPUT "Name of file", filename$
10   fileno = OPENOUT(filename$)
```

Reading from a file of numbers

A file created by the above program could be read and the average of the readings in the file calculated as follows:

```
10   fileno = OPENIN("readings")
20   INPUT# fileno, n
30   sum = 0
40   FOR i = 1 TO n
50     INPUT# fileno, nextreading
60     sum = sum + nextreading
70   NEXT i
80   PRINT "Average: "; sum/n
90   CLOSE# fileno
```

If a file did not include an integer at the start indicating the number of values in the rest of the file, the end of the file could be recognised by using the EOF# function. For example, the average of the numbers in a file with no count at the start could be calculated by

```
10   fileno = OPENIN("readings")
20   sum = 0  : n = 0
30   REPEAT
40     INPUT# fileno, nextreading
50     n = n+1
60     sum = sum + nextnumber
70   UNTIL EOF#(fileno)
80   CLOSE# fileno
90   PRINT "Average: "; sum/n
```

Files containing strings

Strings can also be held as items in a file. For example, the following program sets up a file of strings that represent a piece of text typed at the keyboard.

```
10   fileno = OPENOUT("text")
20   INPUT LINE nextline$
30   REPEAT
40     PRINT# fileno, nextline$
50     INPUT LINE nextline$
60   UNTIL nextline$="****"
70   CLOSE# fileno
```

The user simply types the text a line at a time and types a line containing four stars to terminate the file. The four stars are not sent to the file and any program that reads from the file must use EOF# to recognise the end of the file.

Note that items are held in the file in the same way that they are held in the computer store. This means that each item in the file can only be input to a variable of appropriate type. In particular, if a string has been sent to a file by a statement such as

```
PRINT# fileno, "1, 2, 3"
```

then it can not subsequently be input by a statement such as

```
INPUT# fileno, x, y, z
```

It can only be input as a complete string, for example

```
INPUT# fileno, s$
```

Keeping a parallel array database on file

The use of parallel arrays for representing a simple in-store database was described in Chapters 6 and 7. For example, a simple stock list could be held in arrays declared by

```
DIM refno(100), name$(100), stock(100), priceof(100)
```

These could be initialised from a file by a call of the procedure

```
100   DEF PROCinitialise
110   LOCAL stockfileno, i
120     stockfileno = OPENIN("stockfile")
130     INPUT# stockfileno, sizeofstock
140     FOR i = 1 TO sizeofstock
150       INPUT# stockfileno, refno(i), name$(i),
                              stock(i), priceof(i)
160     NEXT i
170     CLOSE# stockfileno
180   ENDPROC
```

At the end of a run of the program, an updated file could be created by a call of

```
200   DEF PROCcreatenewstockfile
210   LOCAL stockfileno, i
220     stockfileno = OPENOUT("stockfile")
230     PRINT# stockfileno, sizeofstock
240     FOR i = 1 TO sizeofstock
250       PRINT# stockfileno, refno(i), name$(i),
                              stock(i), priceof(i)
260     NEXT i
270     CLOSE# stockfileno
280   ENDPROC
```

Appendix 3 Operator precedence

Precedence level 1

```
+ applied to a single operand (unary plus)
- applied to a single operand (unary minus)
NOT
function calls
bracketed subexpressions
indirection operators ?, !, $ (not covered)
```

Precedence level 2

```
^       raised to the power of
```

Precedence level 3

```
*       times
/       divided by
DIV     divided by (on integers producing integer)
MOD     remainder on dividing two integers
```

Precedence level 4

```
+       plus
-       minus
```

Precedence level 5

```
=       equals
<>      is not equal to
<       is less than
>       is greater than
<=      is less than or equal to
>=      is greater than or equal to
```

Precedence level 6

```
AND     logical and (on truth values or bit patterns)
```

Precedence level 7

```
OR      logical or (on truth values or bit patterns)
EOR     exclusive or (on truth values or bit patterns)
```

Adjacent operators at the same precedence level are dealt with from left to right.

Appendix 4 Summary of mode and colour facilities

Text facilities available in different modes

mode	colours available	characters per line	lines
0	2	80	32
1	4	40	32
2	16	20	32
3	2	80	25
4	2	40	32
5	4	20	32
6	2	40	25

Graphics facilities available in different modes

mode	colours available	graphics resolution
0	2	640 x 256
1	4	320 x 256
2	16	160 x 256
4	2	320 x 256
5	4	160 x 256

Note that there no graphics facilities in modes 3 and 6.

Memory requirements for different modes

mode	memory requirements
0	20K
1	20K
2	20K
3	16K
4	10K
5	10K
6	8K

Overall colour range

There are sixteen actual colours available. These colours are numbered from 0 to 15.

Actual colour numbers and corresponding colours

colour number	colour name
0	black
1	red
2	green
3	yellow
4	blue
5	magenta
6	cyan
7	white
8	flashing black-white
9	flashing red-cyan
10	flashing green-magenta
11	flashing yellow-blue
12	flashing blue-yellow
13	flashing magenta-green
14	flashing cyan-red
15	flashing white-black

Colour codes in different modes

In each mode colours are referred to by code numbers from 0 upwards (using COLOUR for text colour and GCOL for graphics colour). The background colour is set by adding 128 to the required code number. The code numbers for a mode can be made to refer to any combination of actual colours (using VDU 19). There is an initial or default setting for each mode which specifies the colour that you get if you do not use VDU 19.

2 colour mode (MODES 0,3,4,6)

colour code numbers		default actual colours	
foreground	background	colour	number
0	128	black	0
1	129	white	7

4 colour mode (MODES 1 and 5)

colour code numbers		default actual colours	
foreground	background	colour	number
0	128	black	0
1	129	red	1
2	130	yellow	3
3	131	white	7

In the 16 colour mode (MODE 2) the colour codes are initially set to the corresponding actual colour numbers.

Appendix 5 **Bits, bytes and hex**

For the majority of straightforward programming applications, the user of the Electron need not concern himself with the details of how things like numbers and strings are represented inside his computer, but for some advanced applications a more detailed knowledge of the internal representation of information is required.

Bits

All information stored in a modern digital computer is held in the form of 'binary digits'. In this context, the word 'binary' means 'having two possible values', and a binary digit can thus be set to one of two possible values. We usually abbreviate the term binary digit to 'bit'.

When we write a bit on paper, we represent its two possible values as 0 or 1. Inside a computer, a bit might be represented by a magnetic field lying in one of two possible directions, or by an electronic voltage that can be positive or negative. The programmer, however, need not concern himself with the practicalities of representing a bit electronically or magnetically. When he needs to think in terms of the binary representation of information, he can think entirely in terms of ones and zeros.

With one bit, we can represent only two possible values, 0 or 1, and in fact some of the information in our Electron is coded using only one bit. For example, in MODE 4, one bit is used to code the colour of each pixel on the screen. Each pixel can be one of two colours, colour 0 or colour 1.

Bit patterns

Bits are usually organised into groups or 'patterns'. With a group of two bits, each bit can one of two values giving 2x2 possible different patterns.

first bit	second bit	bit pattern
0	0	00
0	1	01
1	0	10
1	1	11

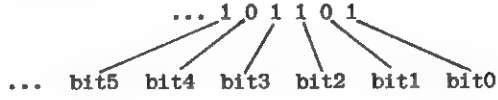
A two-bit pattern is used to code the colour of each pixel on the screen in a four colour mode such as MODE 5.

With three bits, there are 2x2x2 possible different patterns and so on:

no. of bits in pattern	example	no. of possible different patterns
1	0	2
2	10	4 = 2x2
3	011	8 = 2x2x2
4	1010	16 = 2x2x2x2
5	10100	32 = 2x2x2x2x2
6	011010	64 = 2x2x2x2x2x2
7	1101001	128 = 2x2x2x2x2x2x2
8	11000101	256 = 2x2x2x2x2x2x2x2

Bit numbering

The bits in a bit pattern are usually referred to by numbering them from zero upwards from right to left, bit0, bit1, bit2 and so on.



Bytes

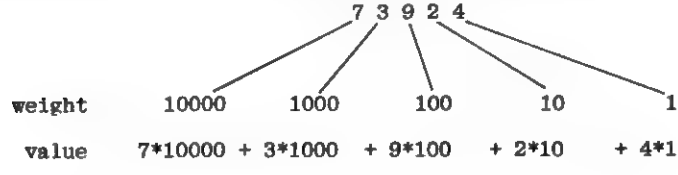
A group of 8 bits is called a 'byte'. One 'word' on your Electron contains one byte or one 8-bit pattern. The entire store that is accessible to the user consists of 32,768 words or bytes of RAM (Random Access Memory). We usually quote storage capacity in 'K' where:

$1K = 1024 \qquad (1024 = 2^{10})$

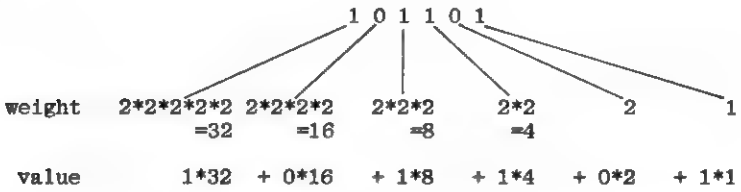
Because we are working on a binary system, everything is organised behind the scenes in powers of 2. Thus we say that the Electron has 32K bytes of store, i.e. 32*1024 bytes or 32*1024*8 bits.

8-bit integers

When we use a group of decimal digits to represent a non-negative integer, each digit has a weight that is a different power of 10. For example, with 5-digits:



When we use a bit-pattern to represent a non-negative integer, only two values are available for each digit, so we give each digit a weight that is a power of 2. For example, with a 6-bit pattern we might have:



When we use a full byte to represent an integer in this way, we have:

binary		decimal
00000000	=	0
00000001	=	1
00000010	=	2
00000011	=	3
:		:
01111110	=	126
01111111	=	127
10000000	=	128
:		:
11111110	=	254
11111111	=	255

We saw earlier that there are 256 different 8-bit patterns and they can be used in this way to represent integers in the range 0 to 255. Because it contributes least weight to an integer, the rightmost bit, bit0, is usually called the least significant bit and the leftmost bit is called the most significant.

8-bit positive and negative integers

If we want to use bytes to represent both positive and negative integers, we have to define a different correspondence between the available bit-patterns and the values they represent. The representation normally used is known as '2s complement' representation. A detailed description of this is beyond the scope of this book, but the next table shows how a byte would be used to represent negative as well as positive integers. The bit-patterns that were previously used to represent positive integers from 128

up to 255 are now used in the same order as before to represent the negative integers from -128 up to -1. In particular, -1 is represented by a bit-pattern that consists entirely of ones. This representation for negative numbers may seem rather strange, but it has many advantages when the computer is doing calculations that involve positive and negative numbers.

binary		decimal
10000000	=	-128
10000001	=	-127
10000010	=	-126
⋮		⋮
11111110	=	-2
11111111	=	-1
00000000	=	0
00000001	=	1
00000010	=	2
⋮		⋮
01111110	=	126
01111111	=	127

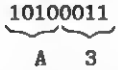
Note that you cannot tell by looking at a bit-pattern what sort of information it is being used to represent. This is determined by the context in which it is used and by the way it is processed by the circuits of the computer. For example, the same bit pattern might be used in different contexts to represent an integer or a character code.

Hexadecimal notation

When we are working with bit-patterns, it becomes very tedious having to write long sequences of ones and zeros when we want to specify a particular bit-pattern. We could abbreviate a byte by writing it as the equivalent positive decimal number, such as 179, but it is not at all obvious if we write 179 that we are talking about the bit-pattern 10110011. When we want to abbreviate a bit-pattern in a way that is not too far removed from its binary form, it is usual to write it in 'hexadecimal' notation (or hex for short). The bit-pattern is first divided into groups of four bits. There are 16 possible different patterns of four bits and each of these possible patterns can be represented by a single 'hexadecimal digit' as follows:

4-bit pattern	hexadecimal digit	4-bit pattern	hexadecimal digit
0000	0	1000	8
0001	1	1001	9
0010	2	1010	A
0011	3	1011	B
0100	4	1100	C
0101	5	1101	D
0110	6	1110	E
0111	7	1111	F

We can thus write the bit-pattern 10100011 in hex as A3:



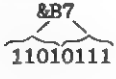
In Electron BASIC, we can write numbers in a program in hex if we precede the number by the symbol '&'. Thus we write &B3. Here are some other examples of bytes and the corresponding hex and decimal numbers:

byte	hex	decimal
00011111	&1F	31
00101110	&2E	46
01101001	&69	105
11111111	&FF	255

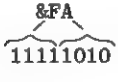
Note that &69 is quite different from decimal 69 which would be represented by the bit-pattern:

01000101 = &85

Because one hexadecimal digit corresponds to four binary digits, it is easy to visualise the bit-pattern corresponding to a hexadecimal number (provided that we are familiar with the sixteen patterns that correspond to the sixteen hex digits). Thus, for example, &B7 is easily visualised as:



and &FA is easily visualised as:



32-bit numbers

A numeric variable in BASIC occupies four computer words which contain four bytes or 32 bits. A number stored in such a variable is coded as a pattern of 32 bits. The way in which a 32-bit pattern is used to represent positive and negative integers is a simple extension of the 8-bit 2s complement representation introduced earlier. Note in particular that -1 is represented by a pattern of 32 ones. Details of how real numbers are coded as bit-patterns are beyond the scope of this book.

Logical operations on bit-patterns

The various logical plotting modes selected by GCOL (Chapter 9) use logical operations on bit-patterns when plotting new information on the screen. For this reason alone, some knowledge of these operations is necessary. The logical operators AND, OR, EOR and NOT treat the values to which they are applied as bit-patterns and operate on the individual bits of these patterns. A detailed knowledge of how these operations work is occasionally useful in advanced programming applications.

When a logical operation is applied to a bit-pattern or to a pair of bit-patterns, the individual bits are handled separately in creating the resultant bit-pattern. AND, OR and EOR are each applied to a pair of bit-patterns of the same length and the result is another bit-pattern of the same length. NOT is applied to a single bit-pattern and the result is another bit-pattern of the same length. We shall illustrate the behaviour of the logical operations on bytes, but they will behave in exactly the same way on shorter or longer bit-patterns.

AND

Each bit in the new pattern is the result of 'anding' the two bits in the same position in the two given bit-patterns according to the following table:

bit1	bit2	bit1 AND bit2
0	0	0
0	1	0
1	0	0
1	1	1

Thus, for example:

```
        byte1          10110100
        byte2          01100101

byte1 AND byte2        00100100
```

OR

Each bit in the new pattern is the result of 'oring' the two bits in the same position in the given bit-patterns according to the following table:

bit1	bit2	bit1 OR bit2
0	0	0
0	1	1
1	0	1
1	1	1

Thus, for example:

byte1	10110100
byte2	01100101
byte1 OR byte2	11110101

EOR

Each bit in the new pattern is the result of 'exclusive oring' the two bits in the same position in the given bit-patterns according to the following table:

bit1	bit2	bit1 EOR bit2
0	0	0
0	1	1
1	0	1
1	1	0

The name of the operator derives from the fact that it 'excludes' the case where both bits to which it is applied are 1. Thus, for example:

byte1	10110100
byte2	01100101
byte1 EOR byte2	11010001

NOT

Each bit in the new bit-pattern is the result of 'negating' the same bit in the given bit-pattern. NOT produces the 'logical inverse' of the given bit-pattern by changing 0s to 1s and 1s to 0s.

bit	NOT bit
0	1
1	0

Thus, for example:

byte	10110100
NOT byte	01001011

Representation of TRUE and FALSE

In Electron BASIC, the value TRUE is represented by a bit-pattern containing nothing but ones and FALSE is represented by a bit-pattern containing nothing but zeros. When these values are stored in numeric variables, they look like the numeric values -1 and 0.

Appendix 6 Print formatting

A PRINT statement contains a list of items that are to be displayed on the screen, the print list. Each item is either a numeric value or a string and the layout of these items on the screen can be controlled by using various punctuation marks in the PRINT statement.

Semicolons in the print list

When a semicolon is used to separate two items in a PRINT statement, the two items are displayed adjacent to each other with no spaces between them.

If the print list starts with a numeric value, then that first value will be treated as if it was preceded by a comma (see below) and extra spaces will appear at the start of the line. These spaces can be suppressed by inserting a semicolon before this first item.

A PRINT statement normally moves the cursor to a new line of the screen after displaying the items in the print list. The next PRINT statement obeyed would then display its items on the new line. A semicolon can be used at the end of a PRINT statement to ensure that the cursor remains on the same line so that the next PRINT statement will display its first item on the same line.

Apostrophes in the print list

The apostrophe, ', can be used anywhere between items in a PRINT statement to move the cursor to a new line before printing the next item.

Commas in the print list

In order to understand the layout produced by using commas in a PRINT statement, we must picture the screen as being divided into vertical strips or 'print fields'. These fields are usually ten characters wide, although this width can be changed by using '@%' (see below).

When a comma is used to separate two items in the print list, this causes enough extra spaces to be inserted to ensure that the item following the comma is displayed at the right hand side of the next print field. This is useful if we want items output by consecutive PRINT statements to be lined up in columns.

If the first item in a print list is numeric, and is not preceded by a semicolon, then that item will be displayed at the right of the first print field. For example,

```
10   PRINT 1,2,3
20   PRINT 2.75,5,7.4
```

will display

```
          1          2          3
       2.75          5        7.4
    └──────┘
       10
    characters
```

Changing the print format: @%

The value of a special variable called @% controls the format used for displaying the items output by a PRINT statement. It is best to use hexadecimal notation for giving a value to @% and for understanding how the value of @% controls the way values are printed. For example,

```
10   @% = &02020A
```

The value of @% is a 32-bit integer which is stored as 4 bytes. We call these four bytes (from left to right) B4, B3, B2 and B1. Each byte corresponds to two hexadecimal digits (see Appendix 5) and in the above example we have B3=&02, B2=&02, B1=&0A. (We shall ignore B4.)

Bytes B3, B2 and B1 each control a different aspect of the formatting of values output by PRINT statements.

B3 selects one of three basic formats:

value of B3	format selected
&00	General or G format: normal format in operation when machine is first switched on.
&01	Exponent or E format: numbers are always printed in scientific notation, for example: 1279.53 as 1.27953E3 0.000571 as 5.71E-4
&02	Fixed or F format: numbers always printed with a fixed number of digits after decimal point.

The effect of byte B2 depends on the basic format currently selected by B3:

basic format currently selected	effect of B2
G format	B2 gives the maximum number of digits that can be printed before reverting to E format.
E format	B2 gives the total number of digits to be printed before the E part, i.e. the accuracy to which numbers are to be printed.
F format	B2 specifies a fixed number of digits to be printed after a decimal point.

Finally B1 specifies the width of the print fields into which the screen is divided.

When the machine is first switched on, @% is set to &00090A (or &90A). This specifies G format; numbers with more than 9 digits to be printed in E notation; the screen is divided into print fields that are ten characters wide.

To print all numbers in fixed point form with two digits after the decimal point, we can use

```
@% = &02020A
```

To print small numbers in columns that are 5 characters wide, with one digit after the decimal point, we can use

```
@% = &020105
```

Appendix 7 Characters, ASCII codes and control codes and Teletext codes

ASCII codes

A character is stored inside the computer as an integer that occupies 8 bits or one byte. There is an internationally agreed standard set of codes for the commonly used characters. These are the ASCII codes (American Standard Code for Information Interchange). The next table contains a list of the common visible characters together with their ASCII codes in decimal and hex.

ASCII characters and their codes

decimal code	hex code	char	decimal code	hex code	char	decimal code	hex code	char
32	&20		64	&40	@	96	&60	`
33	&21	!	65	&41	A	97	&61	a
34	&22	"	66	&42	B	98	&62	b
35	&23	#	67	&43	C	99	&63	c
36	&24	$	68	&44	D	100	&64	d
37	&25	%	69	&45	E	101	&65	e
38	&26	&	70	&46	F	102	&66	f
39	&27	'	71	&47	G	103	&67	g
40	&28	(	72	&48	H	104	&68	h
41	&29	)	73	&49	I	105	&69	i
42	&2A	*	74	&4A	J	106	&6A	j
43	&2B	+	75	&4B	K	107	&6B	k
44	&2C	,	76	&4C	L	108	&6C	l
45	&2D	-	77	&4D	M	109	&6D	m
46	&2E	.	78	&4E	N	110	&6E	n
47	&2F	/	79	&4F	O	111	&6F	o
48	&30	0	80	&50	P	112	&70	p
49	&31	1	81	&51	Q	113	&71	q
50	&32	2	82	&52	R	114	&72	r
51	&33	3	83	&53	S	115	&73	s
52	&34	4	84	&54	T	116	&74	t
53	&35	5	85	&55	U	117	&75	u
54	&36	6	86	&56	V	118	&76	v
55	&37	7	87	&57	W	119	&77	w
56	&38	8	88	&58	X	120	&78	x
57	&39	9	89	&59	Y	121	&79	y
58	&3A	:	90	&5A	Z	122	&7A	z
59	&3B	;	91	&5B	[	123	&7B	{
60	&3C	<	92	&5C	\	124	&7C	¦
61	&3D	=	93	&5D	]	125	&7D	}
62	&3E	>	94	&5E	^	126	&7E	~
63	&3F	?	95	&5F	_			

Control codes

A number of the 256 available character codes are reserved for special purposes on the Electron. Sending one of these codes to the display hardware by using a PRINT or a VDU statement has a special effect. These codes are usually referred to as 'VDU drivers'. Note that some of the codes must always be followed by a fixed number of additional codes or 'parameters'. If these are omitted, the next few characters printed will be taken as the missing parameters.

Summary of VDU codes

decimal	hex	parameters	effect
0	0	0	Does nothing
1	1	1	Printer control (see User Guide)
2	2	0	Printer control (see User Guide)
3	3	0	Printer control (see User Guide)
4	4	0	Separate text and graphics cursors
5	5	0	Join text and graphics cursors
6	6	0	Enable VDU drivers
7	7	0	Beep
8	8	0	Move cursor back one space
9	9	0	Move cursor forward one space
10	&A	0	Move cursor down one line
11	&B	0	Move cursor up one line
12	&C	0	CLS (clear text screen)
13	&D	0	Move cursor to start of current line
14	&E	0	Page mode on
15	&F	0	Page mode off
16	&10	0	CLG (clear graphics screen)
17	&11	1	COLOUR c
18	&12	2	GCOL 1,c
19	&13	5	New actual colour for colour number
20	&14	0	Restore default actual colours
21	&15	0	Disable VDU drivers
22	&16	1	MODE m
23	&17	9	Create user-defined character shape
24	&18	8	Define graphics window
25	&19	5	PLOT k,x,y (2 bytes for x, 2 for y)
26	&1A	0	Restore default windows
27	&1B	0	Does nothing
28	&1C	4	Define text window
29	&1D	4	Define graphics origin
30	&1E	0	Move text cursor to top left
31	&1F	2	MOVE x,y
127	&7F	0	Backspace and delete

These codes can also be sent from the keyboard by typing a CONTROL character - hold down the CTRL key and type the character. For example, codes 1 to 26 correspond to CONTROL-A to CONTROL-Z.

Appendix 8 Notes on program efficiency

The efficiency of a program is a loose term meaning the actual time a program takes to run. A related consideration is the amount of storage space that the program occupies either in store or on disc or cassette. With BASIC the two considerations coincide. Most of the techniques to reduce the run-time of a program also reduce its length and therefore the storage space occupied by it. We are of course referring to the space occupied by the program text and not to space demanded by data structures such as arrays.

Nowadays with the proliferation of personal computers, the run time efficiency of programs is not particularly important in most contexts. There are however situations where the run time efficiency can be critical. Animation is a case in point and the response to a large interactive program is another. In a game playing program such as chess any reduction in execution time, when the machine is responding to a move, is welcome.

In the text of this book the 'transparency' or 'readability' of programs has been a prime consideration. It is generally more important to be able to see the structure or method used, reflected in the program text. To this end we have liberally used such aids as mnemonic or long names.

To illustrate how programs can be made more efficient we start by listing an example program as it may have appeared in the text, and then alter it to make it more efficient.

```
10   MODE 4
20   INPUT xcentre, ycentre, r
30   MOVE xcentre + r, ycentre
40   FOR theta = PI/30 TO 2*PI STEP PI/30
50     xcoord = r*COS(theta)
60     ycoord = r*SIN(theta)
70     DRAW xcentre + xcoord, ycentre + ycoord
80   NEXT theta
```

The following notes itemise how various savings can be made, but we must stress before doing this that such changes should be made only if small increases in execution speed are important. The reduction in readability of the program will probably mean that you spend considerably more time getting it working. Furthermore, returning in the future to an unreadable program to further develop or modify it is a nightmare. Where efficiency is necessary, a useful approach is to keep two versions of a program - a readable version and an efficient version. (In fact the efficient version

could be generated automatically from the readable version!) Remember that, in most cases, the programmer's time is more important than the computer's.

Short names

Although mnemonic names substantially improve transparency, because the program is interpreted on a character by character basis long names carry a run time overhead. In the more efficient version below all the variable names have been contracted to single characters.

Unnecessary assignments

Lines 50 and 60 are technically unnecessary. Any unnecessary assignment carries a run time overhead because it involves an extra memory cycle. Again their inclusion enhances transparency. In the above version of the program you can see immediately the method being used to generate each new coordinate value. For efficiency the arithmetic expressions can be included in line 70 and lines 50 and 60 deleted.

```
70   DRAW xcentre + r*COS(theta), ycentre + r*SIN(theta)
```

Positioning loop independent calculations

Calculations that could be done once before entering a loop should not be included within the loop body. There are no examples of this in the above program, but this can be very important in mathematical programming where complex programs with many nested loops are common. It is easy to inadvertently include loop independent calculations within a loop.

Integer arithmetic

You can force the computer to perform integer arithmetic by appending a '%' to the variable name. For example:

```
a% = 27 : b% = 537
c% = a% * b%
d% = a% DIV b%
```

will execute in approximately a third of the time it takes to execute:

```
a = 27.356 : b = 537.421
c = a* b
d = a/b
```

This is because arithmetic with real numbers invokes extra time overheads. Improvements that can be gained from

converting variables into integer variables (providing the context allows such a conversion) depend on many factors. For example:

```
c = a% * b
```

still uses real arithmetic because the variables are of mixed type, and the integer variable is considered to be a real variable with zero fractional part. However benefits will still result from converting as many variables in an expression to integers as is possible.

The program so far

All the above techniques applied to our original program result in:

```
10   MODE 4
20   INPUT a%, b%, r%
30   MOVE a% + r%, b%
40   s = PI/30
50   FOR t = s TO 2*PI STEP s
60     DRAW a% + r%*COS(t),  b% + r%*SIN(t)
70   NEXT t
```

Lines and spaces

Reduction in the storage space occupied by a program and further minute savings in execution speed can be obtained by eliminating all unnecessary spaces and putting as many statements as possible on each line. This, however, results in complete destruction of readability and should again be used only in a critical context where the savings are really necessary. Note that, when omitting spaces,

```
        x=y   is OK,
       x ANDy is OK,
but    xANDy  is NOT.
```

A space must be maintained when a variable is followed by a keyword. Otherwise in the above example 'xANDy' would be interpreted as a variable name.

Structural efficiency

Now the above modifications could be termed statement efficiency. Another efficiency consideration that can result in dramatic savings is structural efficiency. Is the structure of the program as efficient as it might be? For example in the circle generating program we can change:

```
DRAW a% + r%*COS(t),  b% + r%*SIN(t)
```

to

```
DRAW r%*COS(t), r%*SIN(t)
```

by changing line 30 to

```
25    VDU 29, a%; b%;
30    MOVE r%, 0
```

Altering the structure or method such that the origin is redefined means that we can cut down on the arithmetic in the DRAW statement by a significant amount.

A more drastic alteration is to redefine the algorithm so that calls to the trigonometric routines are avoided.

```
 10   MODE 4
 20   INPUT a, b, r
 30   VDU 29, a; b;
 40   MOVE r, 0
 50   x = r : y = r/10
 60   REPEAT
 70     DRAW x,y
 80     x = x - y/10 : y = y + x/10
 90   UNTIL POINT(x,y) <> 0
100   DRAW x,y
```

The algorithm works as follows: A circle is a curve such that, as it is traced out incrementally, x decreases and y increases in such a way that the decrease in x is a fraction of the current value of y, and the increase in y a fraction of the current value of x (providing the origin is the centre of the circle). This fraction controls the number of times the loop is executed. It has been set equal to 10 so that the number of times the loop is executed (and the number of straight line segments in the circle) is approximately equal to that of the trigonometric algorithm.

Some actual timings

The time reductions achieved by all the above techniques are given below. This is not an unrealistic example and it demonstrates that the most spectacular reductions are usually achieved by changing the algorithm. It also demonstrates that the more efficient algorithms tend to be more obscure and difficult to understand - a fact of life in computer science.

original program	5.07	secs.
statement efficiency	4.88	secs.
structural alteration (redefining origin)	4.72	secs.
structural alteration (redefining circle algorithm)	1.16	secs.

Moral

Short variable names, long lines and removal of spaces destroy the readability of a program and give very slight savings. They should be used only when timing is absolutely critical and are not generally recommended.

Appendix 9 List of Electron BASIC keywords

This appendix contains a complete list of Electron BASIC keywords and a very brief description of each word. The description of a word is intended to be a reminder of what the word does and is not intended to be a detailed specification of the word. Where a word is described in this book, a reference to the chapter or appendix where it is described is given in brackets. For further details, consult the User Guide.

The words are grouped together under different headings and are listed alphabetically under each heading.

Commands

AUTO: Tells the computer to invent line numbers automatically for a program that is being typed.

CHAIN: Used to LOAD and RUN a program from a file.

DELETE (Appendix 1): Deletes lines of a program.

LIST (Appendix 1): Lists all or part of a program.

LISTO (Appendix 1): Changes the layout used when a program is listed.

LOAD (Appendix 2): Loads a program from cassette file into the computer.

NEW (Introduction): Wipes out the old program and prepares for a new one.

OLD: Restores the old program if possible (for example, after a BREAK).

RENUMBER (Appendix 1): Renumbers the lines of the current program.

RUN (Introduction): Runs the current program.

SAVE (Appendix 2): Saves a program on cassette file.

TRACE: Tells the computer to print line numbers as they are obeyed.

Control statements

CALL: Used to call a machine code subroutine.

DEF (7.1): Defines a procedure or function.

ELSE (3.2): Part of an IF-THEN-ELSE statement.

END (7.1): Terminates a run of the program.

ENDPROC (7.1): Terminates a procedure and returns.

FN (7.6): Start of a function name.

FOR (4.1): Start of a FOR-NEXT loop.

GOSUB: Go to a subroutine.

GOTO (3.8): Go to a specified line.

IF (3.1, 3.2): Start of an IF-THEN or an IF-THEN-ELSE statement.

LET: Can be used to introduce an assignment statement.

NEXT (4.1): End of a FOR-NEXT loop.

ON (3.9): Start of an ON-GOTO statement.

PROC (7.1): Start of a procedure name.

REPEAT (4.4): Start of a REPEAT-UNTIL loop.

RETURN: Exit from a subroutine.

STEP (4.3): Part of a FOR statement.

STOP: Stops a program run and reports the line number.

THEN (3.1): Part of an IF statement.

TO (4.1): Part of a FOR statement.

UNTIL (4.4): End of a REPEAT-UNTIL loop.

Keyboard input/output

CLS (8.2): Clears the character screen.

COLOUR (8.2): Specifies a colour for subsequent character printing.

COUNT: A variable that records the number of characters printed since the last new line.

DATA (1.9): Specifies data to be obtained by READ statements.

GET (8.5): Waits and obtains the ASCII code of the next character typed without displaying the character on the screen.

GET$ (8.5): Waits and obtains the next character typed without displaying the character on the screen.

INKEY (8.5): Waits a specified time interval to see if a character is typed. If a character is typed within the time, returns the ASCII code of the character, otherwise returns -1. Can also be used to detect whether a particular key is being pressed at a particular instant (see User Guide).

INKEY$ (8.5): As for INKEY, but returns the character if one is typed within the time specified, otherwise it returns the empty string.

INPUT (1.1): Inputs numbers or strings from the keyboard.

POS: Finds the current horizontal position of the flashing cursor.

PRINT (1.3): Displays a given list of items on the screen.

READ (1.0): Used to obtain data from DATA statements.

RESTORE (1.9): Moves back to the start of the first DATA statement, or to a specified DATA statement.

SPC: Used in a PRINT (or INPUT) statement to print multiple spaces on the screen.

TAB (1.6): Used in a PRINT (or INPUT) statement to move the cursor to a new position.

VDU (8.1): Sends an ASCII code to the screen hardware. If the code represents a printable character, then it is displayed, otherwise it may have a special effect.

VPOS: Finds the current vertical position of the flashing cursor.

WIDTH: Used to set the overall 'page width' that the computer uses.

File input/output

BGET#: Gets a single byte from a file.

BPUT#: Puts a single byte into a file.

CLOSE# (Appendix 2): Closes a file.

EOF# (Appendix 2): Tests for the end of a file.

EXT#: Finds how large a file is (disc files only).

INPUT# (Appendix 2): Inputs items from a file.

OPENIN (Appendix 2): Opens a file for input and allocates a file number for subsequent use by the program.

OPENOUT (Appendix 2): Opens a file for output and allocates a file number for subsequent use by the program.

PRINT# (Appendix 2): Outputs items to a file.

PTR#: Used for random access to a file (disc files only).

Numeric functions and operators

ABS: Function that gives the magnitude of a number, i.e. it removes the minus sign if any.

ACS: Arc cosine function

ASN: Arc sine function.

ATN: Arc tangent function.

COS (2.4): Cosine function.

DEG: Function that converts an angle in radians into degrees.

DIV (2.3): Operator that divides two integers and discards the remainder (if any).

EXP: Function that raises the mathematical constant e (2.7183...) to a specified power.

INT (2.4): Function that converts a real value to the nearest integer value downwards.

LN: Function that calculates logarithms to the base e.

LOG: Function that calculates logarithms to the base 10.

MOD (2.3): Operator that returns the remainder after dividing two integers.

PI (2.4): Constant that has the value 3.14159265

RAD (2.4): Function that converts an angle in degrees into radians.

SGN: Function that returns the sign of a number (-1 means negative, 0 means zero, +1 means positive).

SIN (2.4): Sine function.

SQR (2.4): Square root function.

TAN (2.4): Tangent function.

Functions for string processing

ASC (8.1): Converts a character to its ASCII code.

CHR$ (8.1): Converts an ASCII code into the corresponding character.

EVAL: Evaluates an expression stored in a string.

INSTR (8.5): Tests whether one string contains another one.

LEFT$ (8.5): Picks a specified number of characters from the start of a string.

LEN (8.5): Gives the length of a string.

MID$ (8.5): Picks a specified number of characters starting at a specified point in a string.

RIGHT$ (8.5): Picks a specified number of characters from the end of a string.

STR$ (8.5): Converts a number into its string representation.

STRING$: Generates a long string that consists of a specified number of copies of a shorter string.

VAL (8.5): Generates a number from a string that contains the number in character form.

Logical operators and values

AND (3.6, Appendix 5): Logical 'and' operator.

EOR (3.6, Appendix 5): 'Exclusive or' operator.

FALSE (3.7): The logical value 'false' (represented by the value 0).

NOT (3.6, Appendix 5): Logical 'not' operator.

OR (3.6, Appendix 5): Logical 'or' operator.

TRUE (3.7): The logical value 'true' (represented by the value -1).

Graphics

CLG (9.4): Clear the graphics screen.

DRAW (1.7): Draw a line to a specified point.

GCOL (1.7, 9.4): Select a logical plotting operation and a colour.

MODE (8.2, 9.1): Switch the computer to a specified mode.

PLOT (9.3): Carry out a plotting operation to a specified point.

POINT: A function that gives the colour of a specified point on the screen.

Sound

ENVELOPE (10.7): Used to define an envelope that can then be used for varying the pitch of the sound produced by any SOUND statement that refers to the envelope.

SOUND (1.8, 10.2): Issues a request for a particular sound to be made by the sound generator.

Special variables

HIMEM: Contains the address of the highest memory location available for use by the user's BASIC program.

LOMEM: Contains the address of the storage location above which the computer will store all a BASIC program's variables.

PAGE: Contains the address of the start of the area in which the user's BASIC program is or will be stored.

TIME (4.7): Contains a value that is increased by 1 every one hundredth of a second. Can be reset to any value by the user.

TOP: Contains the address of the top of the user's program.

Miscellaneous

ADVAL: Analogue to digital conversion function. Used to detect the value of one of the voltages at the analogue input socket.

CLEAR: Tells the computer to wipe out the values of all variables previously in use.

DIM (6.1) Allocates space for arrays.

ERL: Gives the number of the line at which an error last occurred.

ERR: Gives the number of the error that last occurred.

LOCAL (7.2): Used to specify that variables are local to a procedure or function.

OPT: Determines the form of output of assembly language programs.

REM (1.7): Introduces a remark or comment intended to make the meaning of a program clearer.

REPORT: Reports in words what the last error was.

USR: Calls a section of machine code program that returns a result.

Appendix 10 Some operating system commands

These commands are all preceded by the character *. We summarise only the commands that have been used in this book. For a complete list you should consult the User Guide.

*CAT: Used to display a list of the files stored on a tape.

*KEY: Used for defining the effect of the user-defined function keys (the red keys at the top of the keyboard - see Appendix 1).

*SPOOL: When followed by the name of a file, this command specifies that all information displayed on the screen should also be sent (in character form) to the file. The file is terminated by issuing a *SPOOL command with no file name.

*EXEC: Reads a specified file of characters and treats them as if they were being typed at the keyboard.

*FX: This command enables the user to control a large number of special effects. The effect controlled depends on the first parameter. Only the *FX calls that have been used in this book are listed.

*FX 4 is used to switch cursor editing on and off. This enables the COPY key and the cursor arrows to be used for other purposes.

```
*FX 4,0 switches on  cursor editing.
*FX 4,1 switches off cursor editing.
```

When cursor editing is switched off, the editing keys generate the following ASCII codes:

COPY	135	(&87)
	136	(&88)
	137	(&89)
	138	(&8A)
	139	(&8B)

*FX 11 is used to set the time delay (in hundredths of a second) before a held-down key 'auto-repeats', i.e. sends repeated copies of the same character to the computer.

```
*FX 11,0 turns off the auto-repeat.
```

*FX 11,t sets the auto-repeat delay to t.

*FX 12 is used to set the time interval between successive auto-repeats of a character.

*FX 12,0 resets auto-repeat behaviour to normal.
*FX 12,t sets time interval between auto-repeats to t.

*FX 21 is used to flush a sound channel queue, ie. terminate any sound being played on a channel and remove any sounds waiting to play.

*FX 21, 4 Flushes the channel 0 sound queue.
*FX 21, 5 Flushes the channel 1 sound queue.
*FX 21, 6 Flushes the channel 2 sound queue.
*FX 21, 7 Flushes the channel 3 sound queue.

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